



**US Army Corps
of Engineers**
Waterways Experiment
Station

Technical Report CHL-98-8
March 1998

Navigation Conditions at Saugus River Floodgate

by Howard E. Park

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Prepared for U.S. Army Engineer Division, New England

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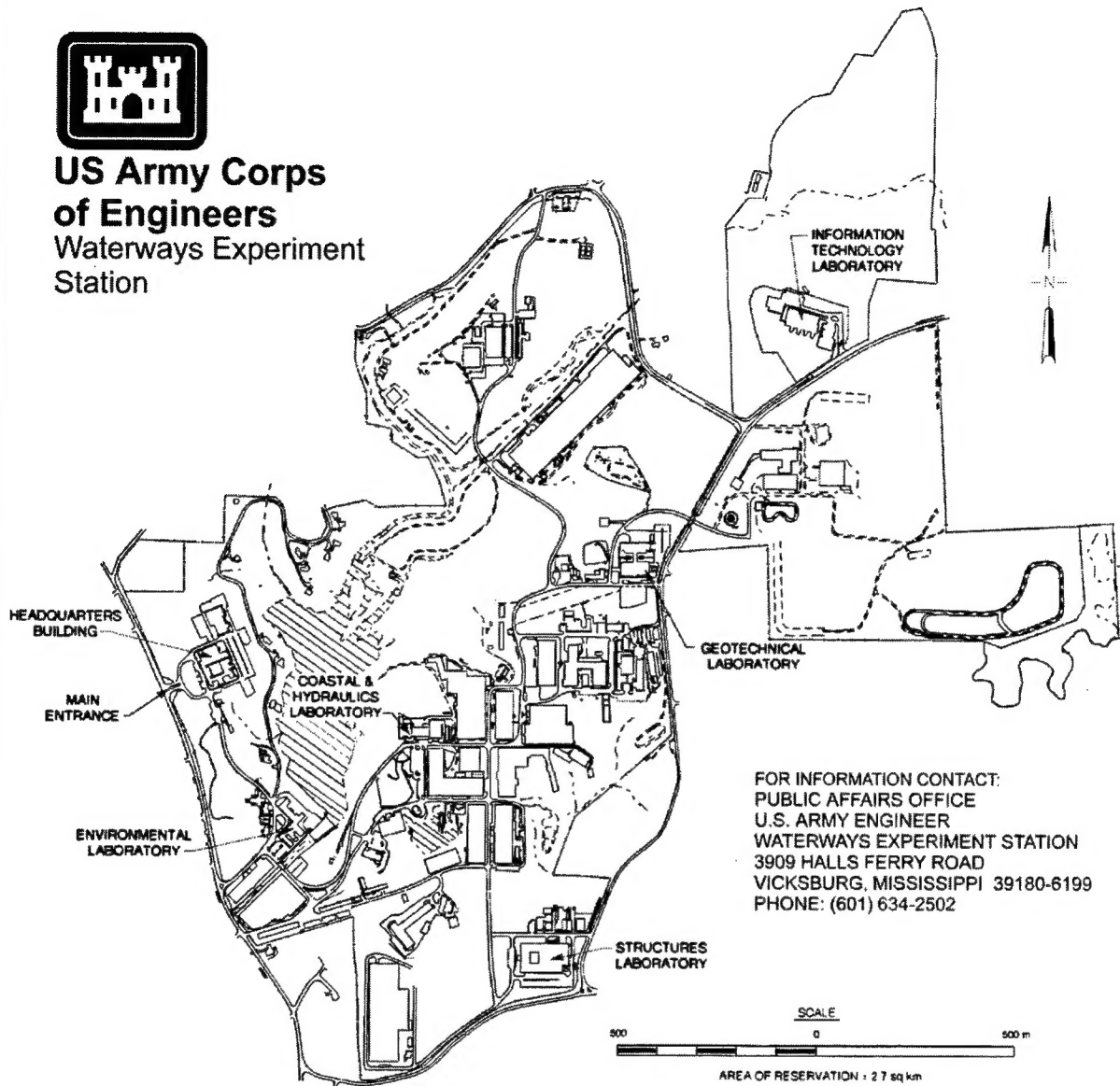
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Waterways Experiment
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Preface

The model investigation described herein was conducted for the U.S. Army Engineer Division, New England, by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The study was conducted in the Hydraulics Laboratory of WES during the period October 1990 to August 1992. In October 1996, the Hydraulics Laboratory merged with the WES Coastal Engineering Research Center to form the Coastal and Hydraulics Laboratory (CHL). Dr. James R. Houston is the Director of the CHL and Mr. Charles C. Calhoun, Jr., is Assistant Director.

During the course of the model study, representatives of the New England Division, Headquarters, U.S. Army Corps of Engineers, and other navigation interests visited WES at various times to observe the model and discuss test results. The New England Division was kept informed of the progress of the study through monthly progress reports and evaluation reports at the end of each test.

The model study was conducted under the direct supervision of Messrs. M. B. Boyd, Chief of the Waterways Division, CHL; and Dr. L. L. Daggett, Chief of the Navigation Branch, Waterways Division. The principal investigator in immediate charge of the navigation portion of the model study was Mr. H. E. Park, assisted by Messrs. E. Johnson, J. Sullivan, K. Green, and J. Cartwright and Ms. D. P. George, all of the Navigation Branch. This report was prepared by Mr. Park.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (U.S. statute)	1.609344	kilometers
square miles	2.589988	square kilometers

1 Introduction

Background

The proposed Saugus River floodgate will be located at the mouth of the Saugus and Pines River estuary. The estuary is about 10 miles¹ north of Boston, MA, along the Atlantic Ocean coast near the cities of Lynn, Malden, and Revere and the town of Saugus, MA (Figure 1). The Saugus River, the Pines River, their tributaries, and the marsh areas comprise a 47-square-mile watershed.

The study area has been hit by five major storms in the past 20 years including the "Blizzard of 1978." The Blizzard of 1978 was estimated to be a 100-year tidal flood event. These storms have caused widespread and very costly damage to commercial and residential developments and transportation arteries in the area. Because of the flooding that has already occurred in the area and the potential for additional flooding and costly damage, the U.S. Army Engineer Division, New England, developed a plan to reduce flood damage from the Standard Project Northeaster (SPN). The plan would consist of the construction of revetment, seawalls, restored sand dunes, and the Saugus River floodgate structure.

The plan is to construct a floodgate structure at the confluence of the Pines and Saugus Rivers near Broad Sound. The structure is to be located about 600 ft seaward of the existing General Edwards Bridge just beyond the Point of Pines Yacht Club. The floodgate will be constructed to maintain safe navigation for commercial and recreational vessels, natural tide levels, and estuary flushing patterns. During storm events that are expected to cause significant damage, the floodgates will be closed. At all other times, the floodgates will be opened.

Need for and Purpose of Model Study

Although the design of the proposed floodgate structure was based on sound theoretical design practice and experience, navigation conditions through the

¹ A table of factors for converting non-SI units of measurement to SI units is found on page vi.

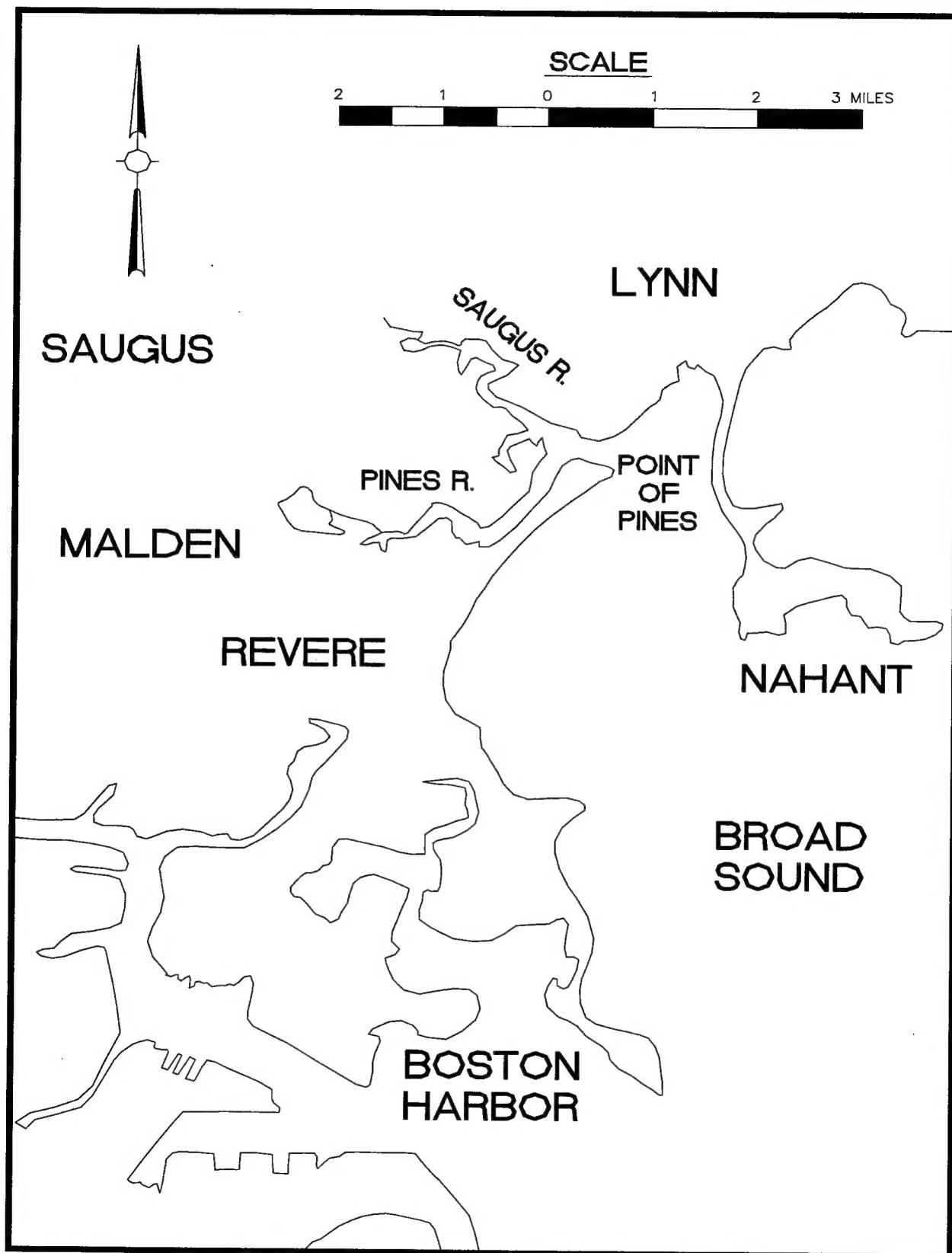


Figure 1. Location map

navigation gate of the structure could be expected to be complex. Navigation conditions would vary with location and flow conditions through the structure, and it was necessary to perform model studies that could account for these effects. Therefore, comprehensive numerical and physical model studies were considered necessary to

- a. Determine the effects of the proposed structure on navigation through the study reach.
- b. Develop modifications to the design of the structure that could improve navigation.
- c. Develop the project construction sequence that would provide satisfactory navigation conditions for small craft.

The model was also used to demonstrate for the design engineers, local sponsors, and navigation interests the conditions resulting from the various alternatives tested, and to satisfy these interests of the design's acceptability from a navigation standpoint.

Group visits were held in March and July of 1992 at the U.S. Army Engineer Waterways Experiment Station (WES) to provide non-Federal interests and U.S. Army Engineer members of the Corps an opportunity to review and comment on both the physical and numerical models and navigation study. On March 9, the non-Federal interests accompanied by representatives of the New England Division and WES reviewed and discussed the physical and numerical models, river currents, and operation/navigation of the model tanker and lobster boat through alternatives of the proposed floodgate structure (Plans 1 and 2C) during flood and ebb tides. On 10 and 11 March, the U.S. Army Engineer District, St. Louis, designers of the floodgate structure, met with the New England Division; Headquarters, U.S. Army Corps of Engineers (HQUSACE); and WES to review the model results and discuss concerns including those raised by the sponsors.

Construction sequencing of the floodgate structure and navigation of the vessels through each phase of construction for both the ebb and flood tides were reviewed in the physical model and discussed on 1 July at a joint meeting with non-Federal sponsors, U.S. Coast Guard, HQUSACE, New England Division, St. Louis District, and WES. The meetings were very productive in identifying and resolving issues and educating representatives of the sponsor and Corps on modeling efforts by WES. Personnel from the New England Division, St. Louis District, and WES held numerous other meetings and maintained contact during the close coordination of the modeling effort. Appendix A lists those attending the group visits to WES.

2 The Model

Description

The physical model reproduced almost 1 mile of the Saugus and Pines River estuary. The physical model extended upstream from the General Edwards Bridge about 700 ft to the confluence of the Pines and Saugus Rivers and continued inland upstream along the Pines and Saugus Rivers about 1,200 ft. The downstream limits of the model reproduced a portion of Broad Sound to a point about 3,000 ft seaward of the General Edwards Bridge. The model also reproduced the adjacent overbank area to contain steady-state flows up to about elevation +10.¹ The model was of the fixed-bed type with the overbank area and the channel molded of sand cement mortar to sheet metal templates set to the proper grade. The bridge, piers, and the floodgate structure were constructed of wood and sheet metal and set to the proper grade. The channel and overbank were molded to conform to a hydrographic survey furnished by the New England Division.

Scale Relations

The model was built to an undistorted linear scale of 1:50, model to prototype. This scale allows accurate reproduction of velocities, eddies, and cross-currents that would affect navigation. The general relations are expressed in terms of the model's scale or length ratio L_r . Other scale relations resulting from the linear scale ratio are as follows.

Characteristic	Ratio	Scale Relation Model:Prototype
Length	L_r	1:50
Area	$A_r = L_r^2$	1:2,500
Velocity	$V_r = L_r^{1/2}$	1:7.071
Time	$T_r = L_r^{1/2}$	1:7.071
Discharge	$Q_r = L_r^{5/2}$	1:17,678
Roughness (Manning's n)	$R_{nr} = L_r^{1/6}$	1:1.92

¹ All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

Measurements of current velocities, discharge, and water-surface elevations can be transferred quantitatively from model to prototype by means of these scale relations.

Appurtenances

Water was supplied to the model by a 5-cfs pump operating in a closed pipe system. The model was not a true tidal model; however, it was capable of reproducing steady flows in both the ebb and flood directions. Flow was introduced or removed from the model via five headbay-tailbays monitored using in-line flow monitors with an accuracy of ± 1.0 percent. Water-surface elevations were measured with point gauges and piezometer gauges located throughout the model.

Velocities and current directions were measured in the model by a video tracking system that tracks a light source attached to floats submerged to the depth of 4.0 ft. Confetti was used to determine surface current patterns. A radio-controlled model tanker (with 11.0-ft draft) and a lobster boat (with 4.5-ft draft) were used to determine and demonstrate the effects of currents on vessels entering and leaving the estuary. The tanker was about 37 by 243 ft. The lobster boat was slightly larger than the prototype boat. The tanker and lobster boat were equipped with single screws and were propelled with an electric motor operating with the batteries in the vessels. The speed and rudders of the vessels were remote-controlled, and the vessels could be operated in forward and reverse at speeds comparable to those that could be expected to be used by the vessels using the estuary. The tanker was used in earlier tests to determine navigation conditions because it indicated more dramatically the impacts of the currents on ship handling. After the best navigation conditions that could be achieved were established, the lobster boat was used to evaluate the navigation conditions. Both the tanker and the lobster boat were operated using minimal power; i.e., the vessels were not overpowered and driven through navigation difficulties. In that way, navigation conditions were such that marginally powered vessels would not be adversely affected by the currents. The path and velocity of the model tanker and lobster boat were measured with the video tracking system.

3 Tests and Results for Project

The primary concerns of the navigation tests were to study the flow patterns, measure velocities, and evaluate the effects of currents on the movement of the model tanker and lobster boat entering and leaving the estuary. These conditions were studied with several alternatives.

Test Procedures

A representative selection of flows was used for testing and was developed using a numerical model of the entire Saugus and Pines estuary including marshy backwater areas. The model, developed at WES,¹ and was used to determine the boundary conditions of the inset physical model. Flows were modeled at the point in the tidal cycle when currents in the project area would be the strongest for flood and ebb flow. Due to the phasing differences between existing and base conditions, the times used as boundary conditions for these two flow conditions were at different points in the tide cycle. The boundary conditions for various flows are shown in the following tabulation.

Tide	Direction	Discharge, cfs	Elevation, ft
Existing Flow Conditions			
Spring	Flood	21,240	3.47
Neap	Flood	8,971	1.46
Spring	Ebb	21,980	4.95
Neap	Ebb	8,005	-0.25
Base Flow Conditions (Influence of Breaching the I-95 Embankment)			
Spring	Flood	22,100	6.23
Neap	Flood	8,330	1.46
Spring	Ebb	22,500	2.92
Neap	Ebb	7,630	-0.25

¹ H. J. Lin, and D. R. Richards. (1993). "Numerical model investigation of Saugus River and tributaries, Massachusetts, flood damage reduction project," Technical Report HL-93-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Current directions were determined by plotting the path of floats with respect to ranges established for that purpose, and velocities were measured by timing the travel of floats over measured distances. In the interest of clarity, only the main trends are shown on plots of currents in turbulent areas or where unsteady currents or eddies existed. Navigation conditions were evaluated and demonstrated using the model tanker and lobster boat. The paths of the model vessels were recorded using the video tracking system.

Existing Conditions

Description

Existing conditions, shown in Figure 2, consist of the following principal features:

- a. The General Edwards Bridge (GEB) with a 100-ft navigation span.
- b. The Point of Pines Yacht Club (PPYC).
- c. The MDC public fishing pier.
- d. The GE Pier (GEP).
- e. A timber pier located opposite the GEP.

Results

Current direction and velocities. Current direction and velocity data are shown in Plates 1-4. Current direction and velocity data for flood flow with the neap and spring tides are shown in Plates 1 and 2. These data indicated that when flow is moving in the flood direction, the flow from Broad Sound is "funneled" into and across the navigation channel. The maximum velocity of the flow moving across the navigation channel was about 2.3 fps¹ with the spring tide and occurred in the general vicinity of the MDC fishing pier; a shallow area extends from the north bank almost to the navigation channel in this area. With the neap tide, the same trend was observed. However, the maximum velocity of the flow moving across the navigation channel was about 0.9 fps. The maximum velocity of flow moving in the flood direction generally occurred in or near the navigation span of the GEB and was 1.2 fps and 2.5 fps with the neap tide and spring tide, respectively.

Current direction and velocity data for flow moving in the ebb direction are shown in Plates 3 and 4. These data indicate that flow is moving across the

¹ Coastal mariners frequently refer to velocity in terms of knots. One knot is approximately equivalent to 1.69 fps.

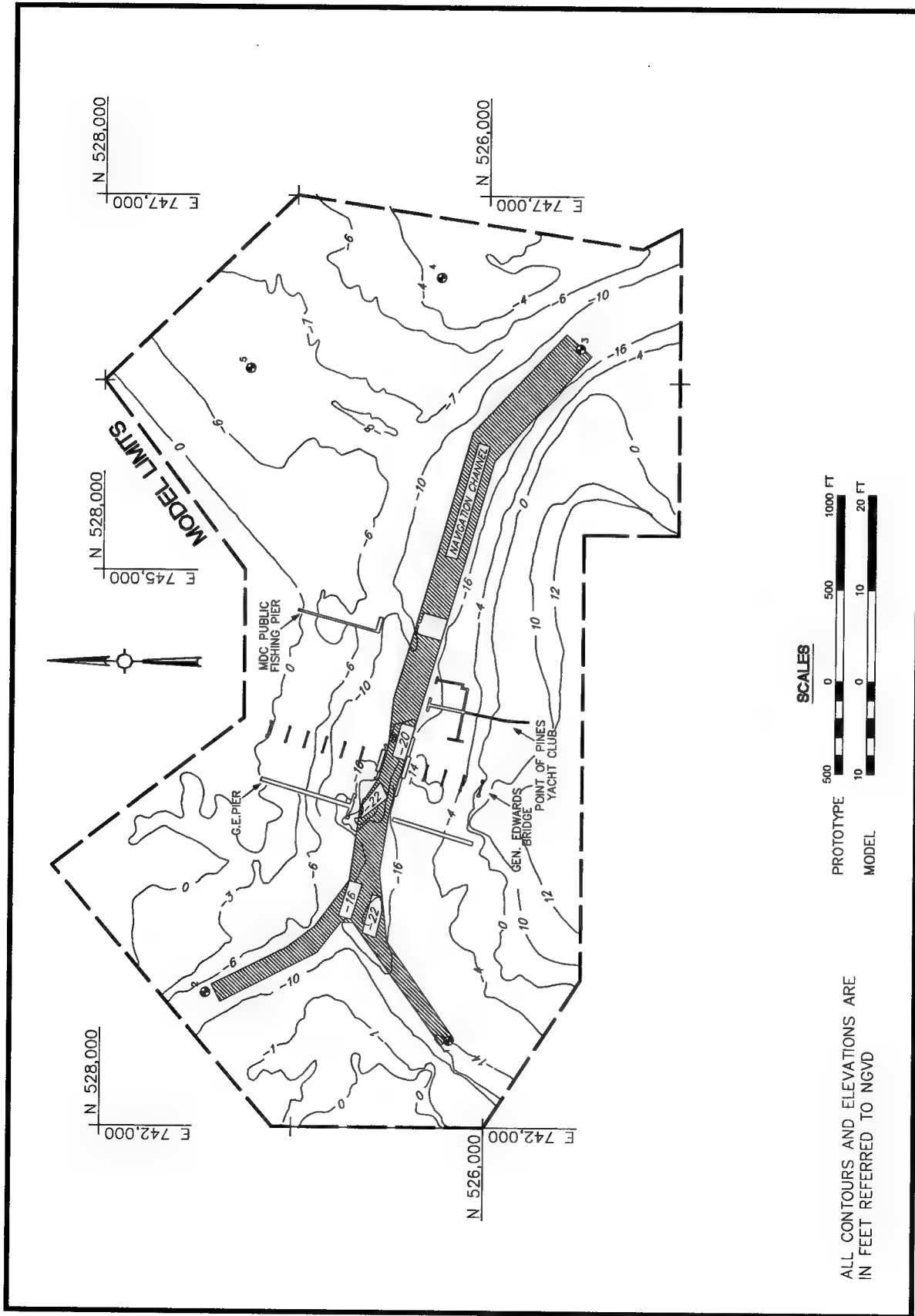


Figure 2. Existing conditions

channel at the navigation span of the GEB with maximum velocities of 1.5 fps and 1.7 fps with the neap tide and spring tide, respectively. With the neap tide, the flow moves into and across the navigation channel just seaward of the PPYC. The maximum velocity recorded in the navigation channel seaward of PPYC was 1.5 fps and 2.1 fps with the neap tide and spring tide, respectively.

Navigation conditions. Navigation conditions were evaluated using the model tanker (Plates 5-14). Navigation conditions were satisfactory with slack tide conditions for inbound and outbound tankers (Plates 5 and 6). Inbound and outbound tankers could approach the navigation span of the GEB and pass through the navigation span with no major difficulties.

With the neap tide and flow in the flood direction, inbound tankers approaching the navigation span of the GEB had a tendency to be moved toward the PPYC by the flow moving across the navigation channel (Plate 7). With the spring tide, there was more tendency for inbound tankers to encroach on the PPYC and become misaligned with the navigation span of the GEB (Plate 8). With the spring tide in particular, it was very difficult for inbound tankers to pass through the navigation span of the GEB because of misalignment seaward of the bridge. It was also difficult for inbound tankers to stay aligned with the Saugus River navigation channel once through the GEB due to currents acting on the stern of the tanker while it was trying to make the turn into the Saugus River. This was more noticeable with the spring tide, but was also evident with the neap tide.

With the neap tide and flow in the flood direction, outbound tankers leaving the Saugus River were required to drive out into the flow entering the Pines River, align with the currents inland of the GEB, and enter the navigation span at an angle to the center line of the bridge span (Plate 9). This maneuver was very difficult due to the limited area in which the tanker had to perform the maneuver. Once inside the protection of the bridge fenders, the tanker could align itself and exit the bridge span. Outbound tankers, once clearing the GEB, experienced a tendency to be moved toward the PPYC due to the crosscurrents in the navigation channel. With the spring tide, navigation conditions for outbound tankers were very much the same as with the neap tide, but more difficult due to higher discharge (Plate 10).

With the neap and spring tides and flow in the ebb direction, inbound tankers could align with the currents seaward of the GEB. Inbound tankers were required to approach the navigation span of the GEB at a slight angle due to the current pattern in the navigation channel. Inbound tankers had a tendency to be moved toward the PPYC. Once through the navigation span of the GEB, inbound tankers experienced a tendency to be moved toward the G.E. Pier by the currents moving out of the Pines River (Plates 11 and 12). Also, making the turn into the Saugus River was difficult due to the flow patterns in the confluence of the two rivers. With the spring tide, navigation conditions for inbound tankers were more difficult due to higher discharge.

With the neap tide and spring tide and flow moving in the ebb direction, navigation conditions were difficult for outbound tankers and in particular with the spring tide (Plates 13 and 14). The flow moving out of the Pines River tended to push outbound tankers leaving the Saugus River toward the G.E. Pier and out of alignment with the navigation span of the GEB (Plate 14). After passing through the GEB, outbound tankers experienced a slight tendency to be moved toward the PPYC.

Base Tests

Description

Base conditions, shown in Figure 3, are the same as existing conditions with one exception. Base conditions included the influence of breaching the I-95 embankment. This breaching of the I-95 embankment caused a change in discharges and water-surface elevations for the spring and neap tides compared with those of existing conditions and also affected the timing of flows due to the way the backwater marsh areas were flooded and emptied. The changes in discharge and water-surface elevation were defined under "Test Procedures," on page 6.

Results

Current direction and velocities. Current direction and velocity data are shown in Plates 15-18. Current direction and velocity data for flood flow with the neap and spring tides are shown in Plates 15 and 16. These data indicate no significant difference in current pattern with the existing neap and spring tides. However, with the spring tide there was a reduction of current velocities compared with those of existing conditions (Plate 2). The maximum velocity of the flow moving across the navigation channel in the vicinity of the MDC fishing pier was about 1.8 fps with base conditions compared with 2.3 fps with existing conditions. The maximum velocity of flow moving in the flood direction generally occurred in or near the navigation span of the GEB and was about 2.1 fps with base conditions and 2.5 fps with existing conditions.

Current direction and velocity data for ebb flow are shown in Plates 17 and 18. With the neap tide, velocities and flow patterns remained about the same as those observed with existing conditions (Plate 3). However, with the spring tide, velocities were increased compared with those of existing conditions (Plate 4). The maximum velocity recorded for base conditions in or near the navigation span of the GEB was 2.8 fps compared with 1.9 fps with existing conditions. Also, the maximum velocity recorded in the navigation channel seaward of PPYC for base conditions was 3.0 fps compared with 2.1 fps with existing conditions. With the spring tide and ebb flow, the current patterns inland of the GEB and the G.E. Pier were distinctly different from those observed with the existing conditions. The flow out of the Pines River appears to be more predominant

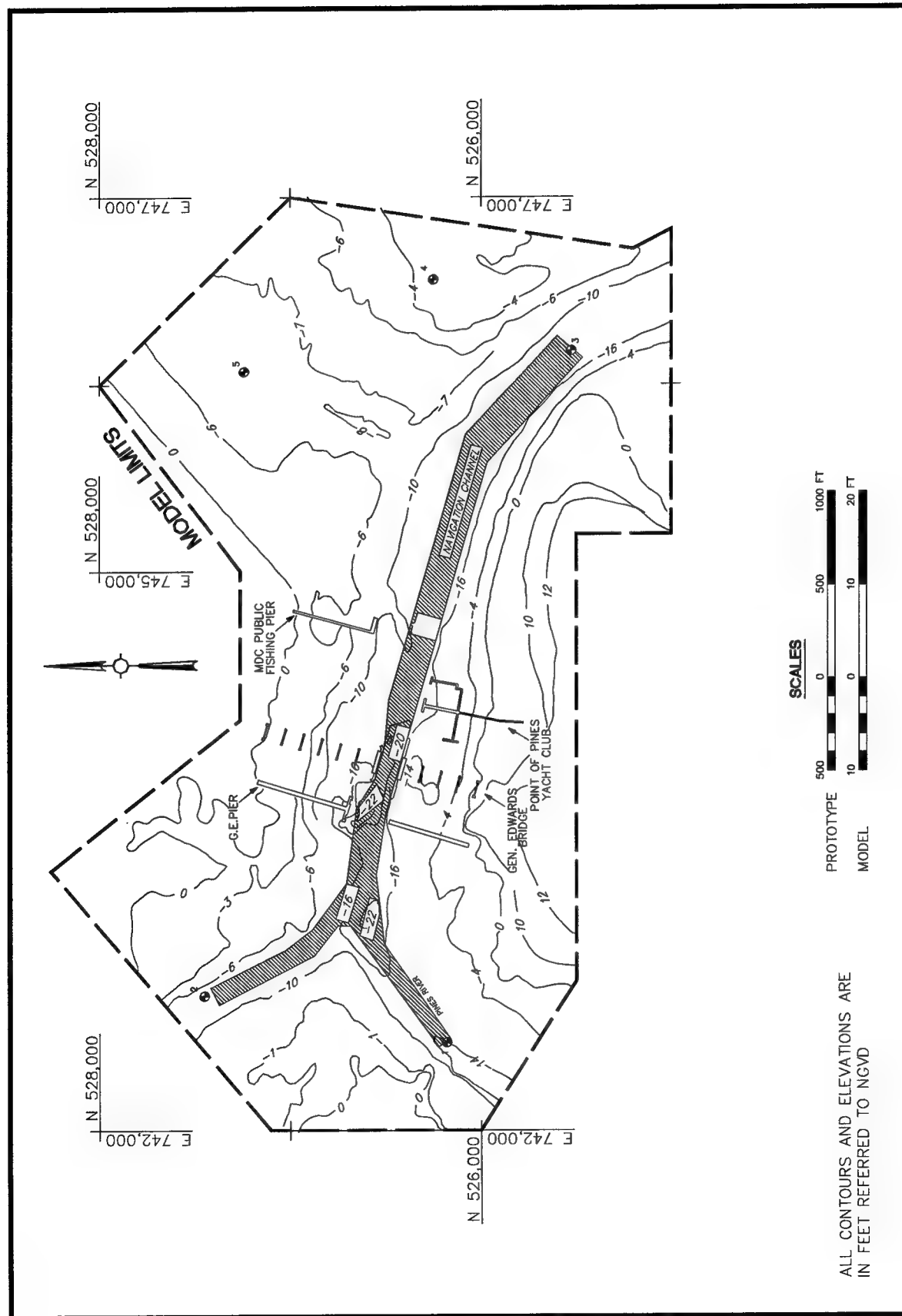


Figure 3. Base conditions

than those observed with existing conditions and the crosscurrents at the confluence of the two rivers appear to be stronger and extend further up into the Saugus River.

Navigation conditions. Navigation conditions were very much the same as those observed with existing conditions (Plates 8 and 10) with the spring tide and flow in the flood direction (Plates 19 and 20). However, with the spring tide and flow moving in the ebb direction (Plates 21 and 22), velocities were increased with more crosscurrents at the confluence of the Pines and Saugus Rivers, and navigation conditions were more difficult than those observed with existing conditions (Plates 12 and 14).

Plan 1

Description

Plan 1, shown in Figure 4, is the same as the base condition with a few exceptions:

- a. The proposed floodgate structure was installed. The floodgate structure as originally designed consisted of a 100-ft-wide navigation gate, nine 50-ft-wide flushing gates on the north side of the navigation gate and one 50-ft-wide flushing gate on the south side. The sill elevation of the navigation gate was at -18 ft and the flushing gate sills were at -14 ft.
- b. Also included was a dredged channel at el -14 on the north side of the navigation gate in the vicinity of the nine flushing gates. With Plan 1, the influence of breaching the I-95 embankment was included, i.e., base boundary conditions.

Results

Current direction and velocities. Current direction and velocity data are shown in Plates 23 and 24. Data were recorded for the spring tide only. With the spring tide and flood flow, currents in the navigation channel seaward of the floodgate structure were more aligned with the navigation channel than those observed with base conditions. Velocity magnitudes in this area remained about the same as those observed with base conditions. However, velocities at the navigation gate of the structure were increased from about 1.8 fps with base conditions to 2.4 fps with Plan 1. Also, there are some crosscurrents at the navigation gate. Just inland of the flood-control structure, on the south side near the PPYC, a large counterclockwise eddy was observed. In the navigation channel between the GEB and the flood-control structure, crosscurrents were stronger than were observed with base conditions. The data also show higher velocity currents in the first bridge span south of the navigation span of GEB with Plan 1 than with the base condition. In general, with Plan 1, velocities in the navigation

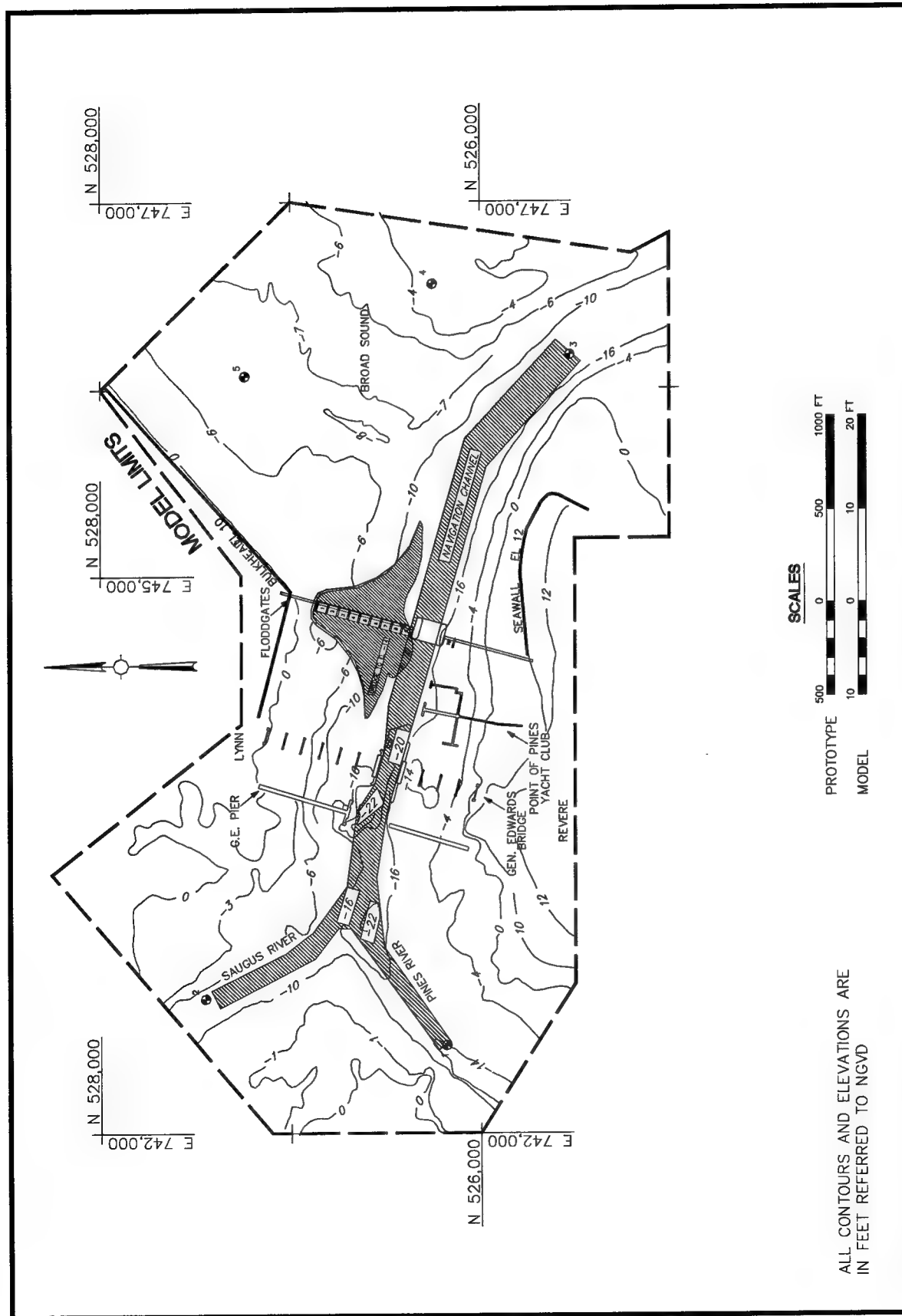


Figure 4. Plan 1

channel between the GEB and the flood-control structure were increased about 0.5 and 0.9 fps.

With the spring tide and ebb flow, velocities inland of the floodgate structure in the navigation channel were increased by about 0.5 and 0.9 fps compared with those of base conditions. Also, in the navigation channel seaward of the flood-gate structure, velocities were increased by about 0.7 fps compared with those of base conditions. A noticeable difference between base conditions and Plan 1 is the flow pattern inland of the flood-control structure. The flow across the out-bound approach to the GEB and through the navigation span of the GEB was stronger than observed with base conditions. Strong crosscurrents were observed in the navigation channel between the GEB and the flood-control structure as the higher velocity currents moved across the navigation channel seaward of the GEB toward floodgates 8 and 9 on the north side of the navigation gate. With base conditions, the higher velocity currents moved more or less parallel to the navigation channel seaward of the GEB. With Plan 1, seaward of the flood-control structure, a slight change in flow pattern was observed in the navigation channel and along the south shore. There was a tendency for the flow in the navigation channel to move toward the south shore.

Navigation conditions. With the flood-control structure in place, navigation conditions were not satisfactory for the tanker for inbound or outbound movements for the spring tide ebb or flood flows. With flood flow and the spring tide, crosscurrents were observed in the navigation gate of the flood-control structure and in the navigation channel between the GEB and the flood-control structure. These crosscurrents moved inbound tankers slightly out of alignment at the structure (Plate 25). In the navigation channel between the two structures, the crosscurrents moved the tanker out of alignment with the navigation span of the GEB. The tanker experienced a strong tendency to be pushed into the south side GEB bridge fender (Plate 25). Navigation conditions for outbound tankers were very much the same as those observed with base conditions with a couple of exceptions (Plate 26). The crosscurrents seaward of the GEB were at a larger angle and magnitude, which caused outbound tankers to take more set to align with the flood-control structure. The set of the vessel is the orientation the vessel is required to take to overcome the effects of currents. There was also a slightly different set exiting the flood-control structure. Strong currents through the navigation structure caused the tanker to slow significantly and require extra power to complete the transit out of the structure.

With the spring tide and ebb flow, navigation conditions were very much the same as those observed with base conditions with one exception. Strong cross-currents were observed between the GEB and the flood-control structure. These currents were moving from the south side of the navigation channel toward floodgates 8 and 9. Inbound tankers were moved toward the north after exiting the flood-control structure due to these crosscurrents (Plate 27). This caused some difficulty in aligning with the GEB. Navigation conditions were not satisfactory for outbound tankers (Plate 28). Navigation conditions approaching the GEB were like those observed with base conditions. However, once clear of the GEB, the crosscurrents moved the tanker out of alignment with the

navigation gate in the flood-control structure (Plate 28). Outbound tankers experienced a strong tendency to be pushed into the north pier of the navigation gate. Also, once the tanker was through the navigation gate, the flow moving toward the south shore tended to move the tanker in a southerly direction. Thus, a different set from that approaching the navigation structure was required to maintain course in the channel.

Plan 2

Description

Plan 2, shown in Figure 5, is the same as Plan 1 with several exceptions:

- a. Two additional floodgates were placed on the south side of the navigation gate, for a total of three gates on the south shore.
- b. Four gates were removed on the north side of the navigation gate, for a total of five gates on the north shore.
- c. A dredged approach at el -14 was placed both seaward and inland of the three gates on the south shore.
- d. The area dredged on the north side was reduced such that it was normal to the flood-control structure at gate 1. With Plan 2, the influence of breaching the I-95 embankment was also included, i.e., base boundary conditions.

Results

Current direction and velocities. Current direction and velocity data are shown in Plates 29 and 30. With the spring tide and flood flow, crosscurrents were observed in the navigation channel seaward of the flood-control structure compared with Plan 1. The flow moved from the north across the navigation channel toward the south gates (gates 6-8), thus creating crosscurrents seaward of the flood-control structure. Current magnitudes in this area were increased. Along the south shore, current magnitudes were increased by about 0.5 fps compared with those for Plan 1. Current magnitude in the navigation gate was increased from 2.4 fps with Plan 1 to 2.9 fps with Plan 2. The currents in the navigation channel between the GEB and the flood-control structure appeared to be fairly straight with some slight irregularities due to the nature of turbulent flow. Current magnitudes in the navigation channel between the GEB and the flood-control structure remained about the same compared with those of Plan 1. With Plan 2, current patterns and magnitudes along the north and south shores inland of the flood-control structure were different compared with those of Plan 1. The large eddy observed at the PPYC with Plan 1 was reduced in size.

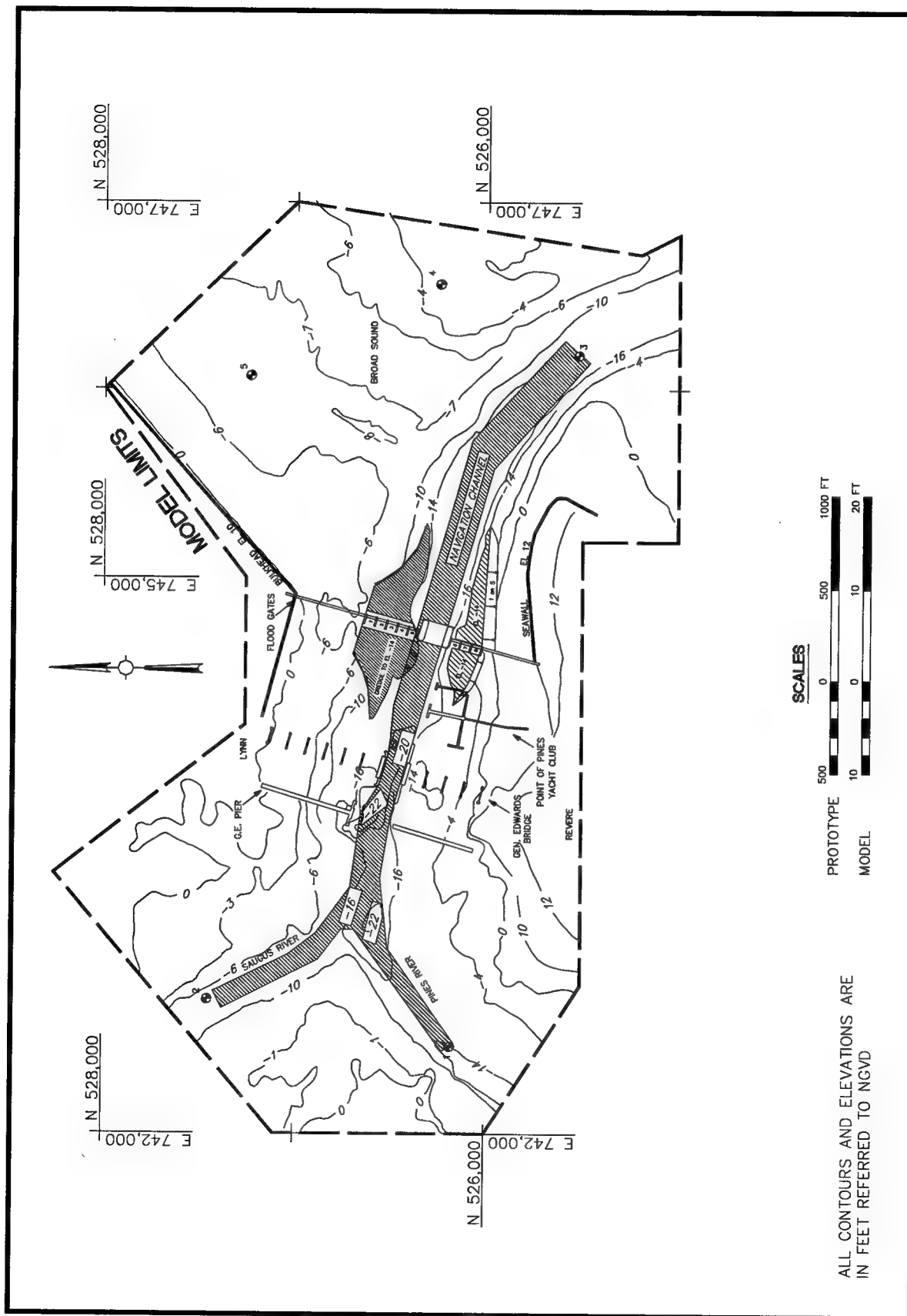


Figure 5. Plan 2

The flow through gates 6, 7, and 8 moved more nearly parallel with the south shore. The additional two gates on the south side provided a more even flow distribution inland of the flood-control structure. Current magnitudes in this area increased by about 0.5 fps compared with those of Plan 1. In general, current magnitudes along the north shore inland of the flood-control structure were increased by about 0.5 fps compared with those of Plan 1.

With the spring tide and ebb flow, currents were aligned with the navigation channel between the GEB and the flood-control structure. However, there was an increase in current magnitudes in this area compared with those of Plan 1. Current magnitudes just inland of the navigation gate were increased from about 2.2 fps with Plan 1 to 3.0 fps with Plan 2. Also, the current magnitudes along the south shore were increased compared with those of Plan 1. Current magnitudes along the south shore near the PPYC were about 1.1 fps with Plan 2 compared with less than 0.5 fps with Plan 1. Only slight differences were observed in current magnitudes along the north shore between Plans 1 and 2. Current magnitudes in the navigation gate remained about the same as those observed with Plan 1. The flow leaving the flood-control structure toward Broad Sound moved almost parallel to the navigation channel. With the additional south gates, current magnitudes along the south shore seaward of the flood-control structure were increased by about 0.8 fps compared with those of Plan 1. Also, the eddy or slack-water area observed with Plan 1 was not observed with Plan 2. With Plan 2, current magnitudes north of the navigation channel and seaward of the flood-control structure increased by about 0.5 fps compared with those of Plan 1.

Navigation conditions. Navigation conditions are shown in Plates 31-34. With the spring tide and flood flow, navigation conditions for inbound tankers were not satisfactory (Plate 31). Inbound tankers that aligned with the navigation gate about 700 ft seaward of the navigation gate were moved out of alignment due to the crosscurrents in the navigation channel. However, navigation conditions between the navigation gate and the GEB were satisfactory. The flow in this area moved almost directly down the navigation channel and through the navigation span of the GEB. Therefore, if inbound tankers could achieve satisfactory alignment exiting the navigation gate, they could align with and pass through the navigation span of the GEB with no significant difficulties.

With spring tide and flood flow, navigation conditions were improved compared with those of Plan 1 and were considered satisfactory for outbound tankers provided sufficient maneuvering area is provided south and seaward of the navigation gate and south of the navigation channel. Outbound tankers could approach and pass through the navigation span of the GEB, align with the navigation gate, and exit the navigation gate with no significant difficulties (Plate 32). Navigation conditions exiting the flood-control structure were similar to those observed with Plan 1. Outbound tankers were required to set into the crosscurrents (flow moving toward the south gates) to complete the transit of the navigation gate. Because the ship could not begin adjusting to the currents while in the gate structure, the ship drifted to the south and out of the authorized

navigation channel before regaining control. It should be noted that additional power was required to complete the transit of the navigation gate.

With spring tide and ebb flow, navigation conditions were not satisfactory for outbound tankers approaching the GEB, which was the case with all other tests (Plate 33). However, navigation conditions between the GEB and the flood-control structure were improved and considered satisfactory compared with those of Plan 1. If proper alignment could be achieved exiting the navigation span of the GEB, outbound tankers could align with the navigation gate and pass through the flood-control structure without significant difficulties.

Navigation conditions were satisfactory for inbound tankers with the spring tide and ebb flow (Plate 34). Inbound tankers approaching the navigation gate were required to take a set into the flow, enter the navigation gate, and proceed toward the GEB. As previously mentioned, the flow between the two structures is fairly straight and navigation conditions were improved compared with those of Plan 1. Navigation conditions exiting the GEB were very similar to those observed with all other tests.

In an effort to improve navigation conditions seaward of the flood-control structure, a couple of intermediate tests were performed in an attempt to eliminate or reduce the crosscurrent for flow in the flood direction. These tests included extensive dredging in the Broad Sound area. The configurations of these plans, designated as Plan 2A and Plan 2B, are shown in Figures 6 and 7, respectively. The resulting current direction and velocity data for each of these tests are shown in Plates 35-37. No improvements in the approach conditions to the navigation gate from the seaward side were obtained. This included making extensive changes in the flow distribution in the headbays of Broad Sound to determine the sensitivity of the flow distribution near the floodgate structure to the boundary conditions. Tests were also performed with various flow guidance structures (dikes) with no significant benefits.

Plan 2C, Bottom Gate el +3

Description

Plan 2C with bottom of the gate at el +3, shown in Figure 8, is the same as Plan 2 with a few exceptions:

- a.* The excavated approach channel to floodgates 1-5 (on the north shore) was revised from that with Plan 2. The excavation extended seaward of and normal to the structure about 400 ft at el -14.0.
- b.* The excavated approach channel to floodgates 1-5 also extended inland of and normal to the structure about 400 ft at el -14.0.

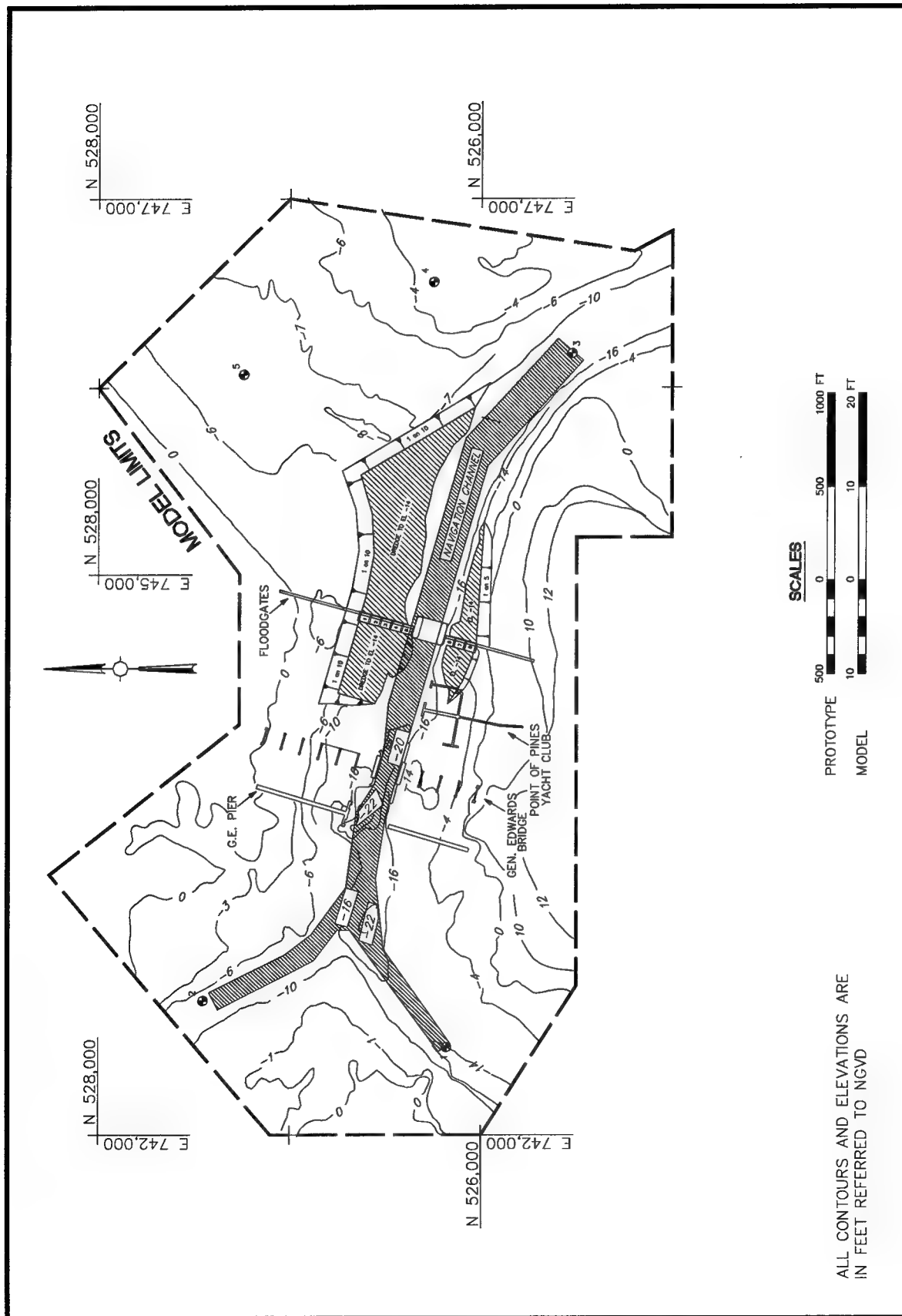


Figure 6. Plan 2A

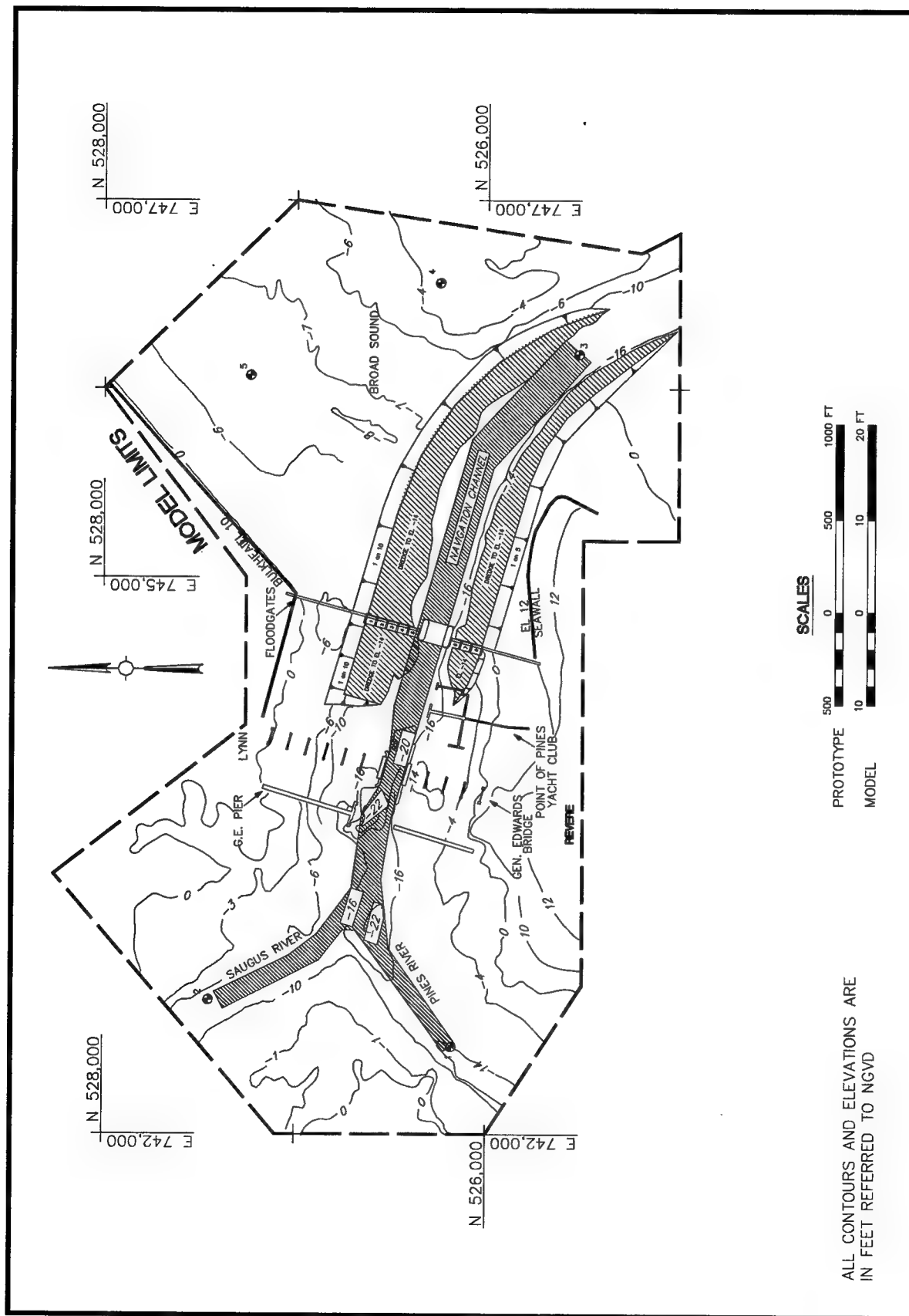


Figure 7. Plan 2B

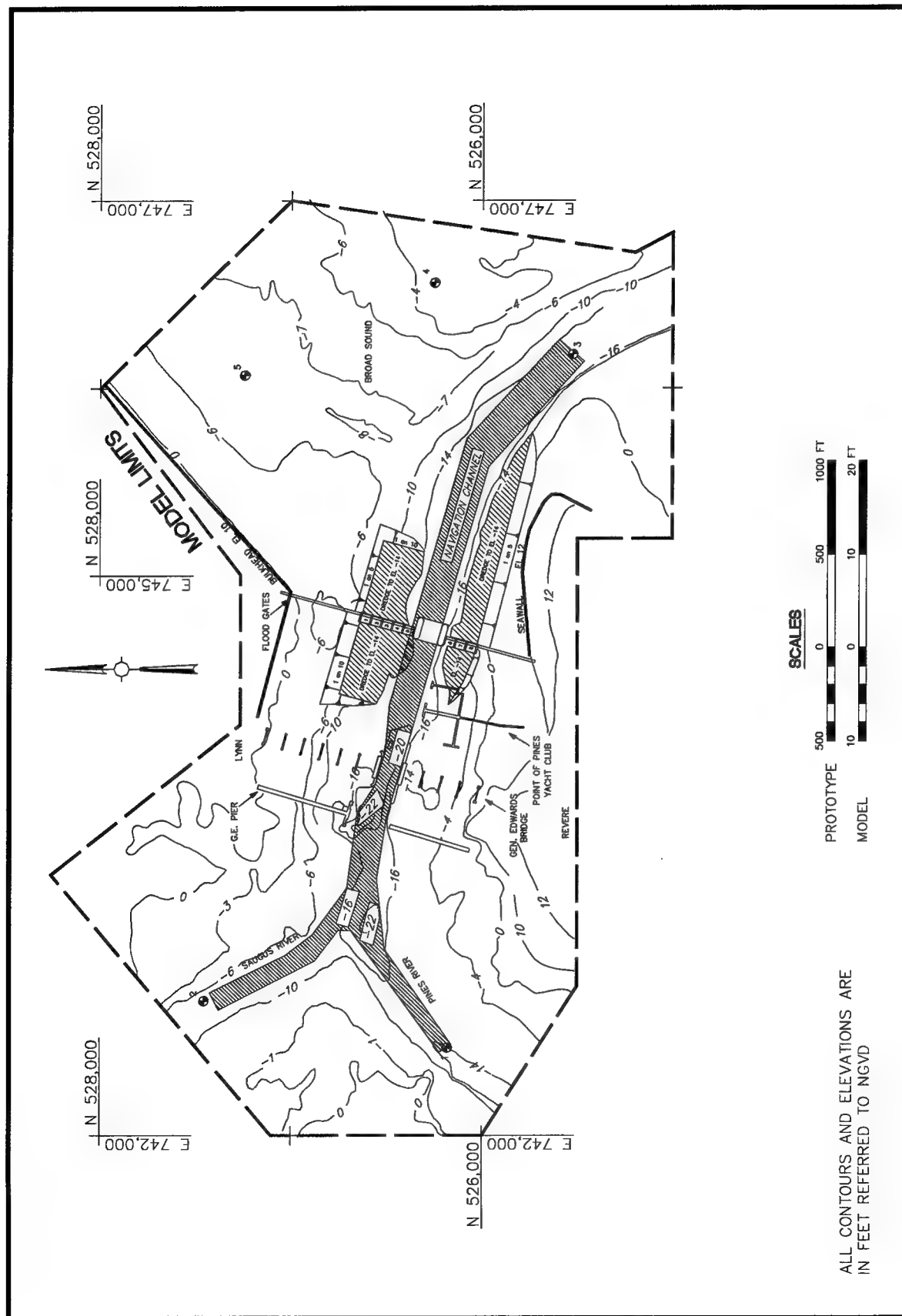


Figure 8. Plan 2C, Bottom gate el +3

- c. The excavated approach channel on the south shore of the structure (gates 6-8) extended seaward about 1,150 ft at el -14.0 ft.
- d. The tainter gates in the raised position were at el +3.0 ft. With Plan 2C +3, the influence of breaching the I-95 embankment was also included.

Results

Current directions and velocities. Current direction and velocity data are shown in Plates 38 and 39. These data indicate some changes in current magnitudes in the vicinity of the navigation gate and in the navigation channel seaward of the flood-control structure compared with those of Plan 2. This was noted in particular with the spring tide and flow in the ebb direction (Plate 39). In particular, velocity magnitudes were increased slightly in the navigation channel at the GEB, navigation gate, and the channel between these structures.

Navigation conditions. Navigation conditions are shown in Plates 40-43. Navigation conditions were about the same as those observed with Plan 2.

Plan 2C, Bottom Gate el +7

Description

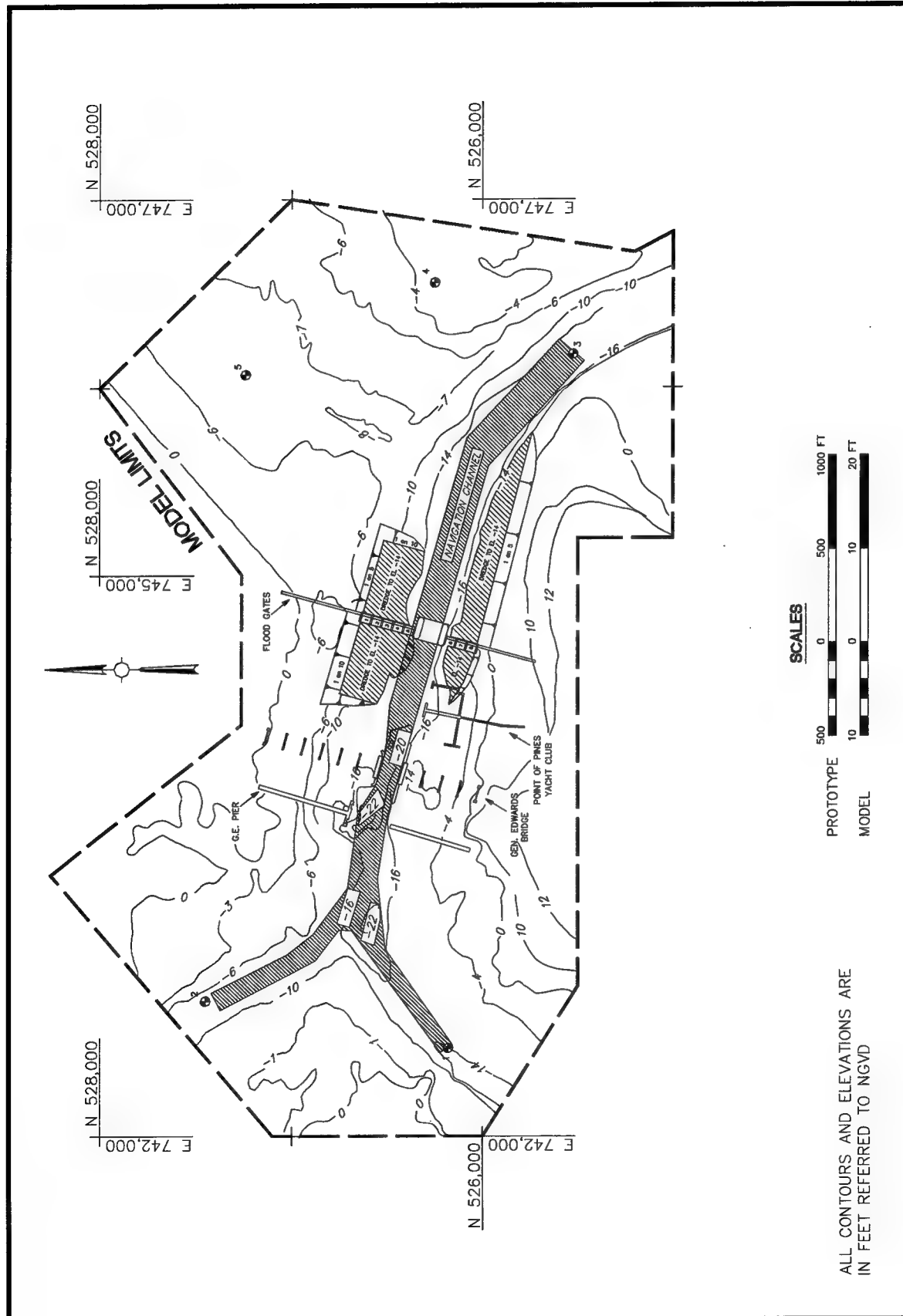
Plan 2C with the bottom of the gate at el +7, shown in Figure 9, is the same as Plan 2C with the bottom gate at el +3, with two exceptions.

- a. The bottom of the breast wall was set to el +7.
- b. The bottom of the tainter gate in the raised position was at el +7.

With Plan 2C +7, the influence of breaching the I-95 embankment was also included. Elevations of the bottom of the gate and bottom of the breast wall were raised to reduce the potential blockage of ice flowing through the flood-control structure.

Results

Current direction and velocities. Current direction and velocity data are shown in Plates 44-47. Current direction and velocity data for the spring tide and neap tide for flood flow (Plates 44 and 45) indicate the same general flow pattern as those observed with Plan 2C +3 and only slight variances in current magnitude. A north-to-south crosscurrent was observed approaching the navigation gate. The maximum current magnitude recorded in the navigation gate ranged from 1.6 fps to 3.4 fps with the neap and spring tides, respectively. The maximum current magnitude recorded in the navigation channel between the



GEB and flood-control structure ranged from 1.6 fps to 2.9 fps with neap and spring tides, respectively. The maximum current magnitude recorded in the navigation span of the GEB ranged from 1.5 to 2.9 fps with the neap and spring tides. In general, the flow moved parallel to the navigation channel between the GEB and flood-control structure.

With the neap and spring tides for ebb flow, current direction and velocity data (Plates 46 and 47) indicate no significant changes in current pattern or current magnitude compared with those of Plan 2C +3. The maximum current magnitude recorded in the navigation span of the GEB ranged from about 1.7 to 3.3 fps with the neap and spring tides, respectively. The flow moved generally parallel to the navigation channel between the GEB and flood control structure, and the maximum current magnitude recorded in this area ranged from about 1.6 to 3.5 fps with the neap and spring tides, respectively. The maximum current magnitude recorded in the navigation gate of the flood-control structure ranged from about 1.8 to 4.0 fps with the neap and spring tides, respectively. In general, the flow moved parallel to the navigation channel upon exiting the navigation gate.

It was also noted that by raising the tainter gates above tidal water surface, the eddies and vortices that formed near the gates were reduced.

Navigation conditions. Navigation conditions for small vessels are demonstrated in Plates 48-51, which show multiple tracks of the remote-controlled lobster boat for the spring tide only. Navigation conditions were satisfactory for inbound and outbound traffic with the spring tide and flood flow (Plates 48 and 49). Inbound traffic could align with the navigation gate about 600 ft seaward of the flood-control structure, enter the navigation gate, align with the navigation span of the GEB, and enter and pass the GEB with no significant difficulties (Plate 48). However, it should be noted that a crosscurrent existed in the navigation channel approaching the flood control structure, and its effects (a slight drift toward the south) on inbound traffic are shown in Plate 48.

Navigation conditions were satisfactory for outbound traffic with the spring tide and flood flow (Plate 49). Outbound traffic could align with the flow and pass through the navigation span of the GEB and the navigation gate of the flood-control structure with no significant difficulties.

With the spring tide and ebb flow, navigation conditions were satisfactory for inbound and outbound traffic (Plates 50 and 51). Inbound traffic could align with the flow and pass through the navigation gate of the flood-control structure and the navigation span of the GEB with no significant difficulties (Plate 50).

With the spring tide and ebb flow, navigation conditions for outbound traffic were satisfactory (Plate 51). Outbound traffic experienced some difficulties approaching the navigation span of the GEB. However, once through the GEB, outbound traffic could align with and pass through the navigation gate of the flood-control structure with no significant difficulties.

Additional testing was requested by the New England District to investigate reducing the extent of the dredging along the south shore on the Broad Sound side of the floodgate structure. The results of these tests are found in Appendix B of this report.

Construction Sequence

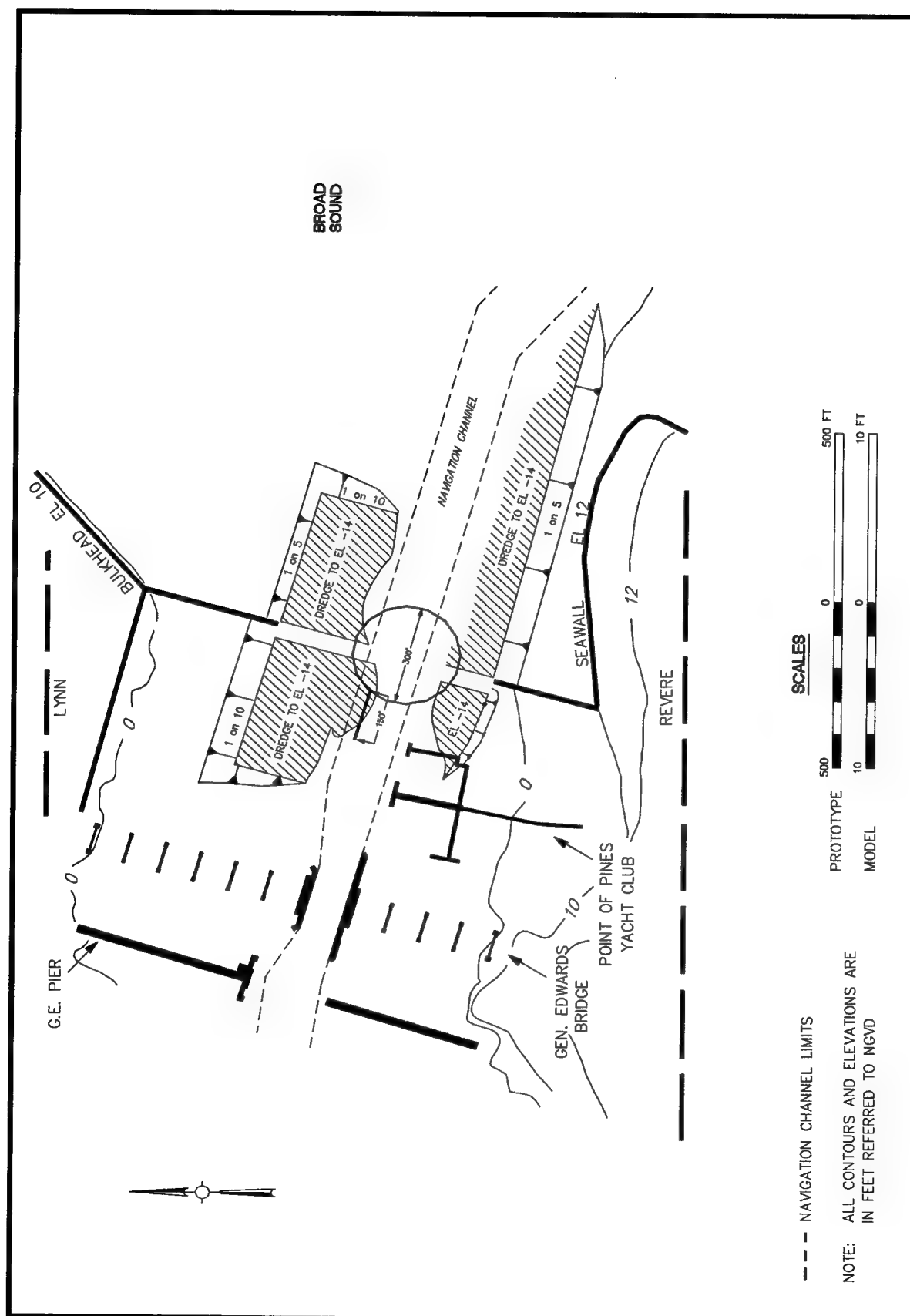
The Saugus River floodgate is to be constructed in four phases. However, prior to construction of the structure itself, all underwater dredging is to be accomplished. The primary concern of these tests was to evaluate navigation conditions and collect current direction and velocity data for several alternatives of the construction sequence for the final plan (Plan 2C with bottom gate el +7). All data and evaluations of navigation conditions were recorded for existing flow conditions, i.e., without the I-95 embankment cut. Three alternatives were addressed and discussed, some in more detail than others. The various alternatives tested are designated Alternatives 1, 2, and 3 for use in this report. Alternatives 1 and 2 are very similar in the way in which the project would be constructed. Alternative 3 is a different construction scheme from Alternatives 1 and 2. Since Alternative 2 is considered to create the most difficult navigation conditions due to the reduction in cross-sectional area and thus higher current magnitudes, this alternative was tested extensively. Alternative 1 was then evaluated based on an analysis of the results of tests with Alternative 2.

Alternative 2

Description

Construction sequence, alternative 2 (CSA 2), is shown in Figures 10-13. CSA 2 would require constructing the project in four stages (stages 1, 2, 3, and 4 construction). Prior to the actual building of the structure itself, all dredging would be accomplished first. Then actual construction of the structure would follow. A description of each stage of construction follows:

- a. Stage 1, shown in Figure 10, is the construction of a 300-ft-diam circular cofferdam in which the navigation gate would be constructed. A "splitter" wall would be constructed and would extend 150 ft from the outer edge of the circular cofferdam toward the GEB. The splitter wall would be aligned with the center line of the north pier of the navigation gate. The splitter wall would remain in place during the entire construction of the project. Also, the concrete gravity walls extending from the north and south shores out to the "end" tainter gates would be constructed simultaneously with the circular cofferdam.
- b. Stage 2, shown in Figure 11, would begin after the circular cofferdam is removed. Stage 2 would require construction of a square cofferdam



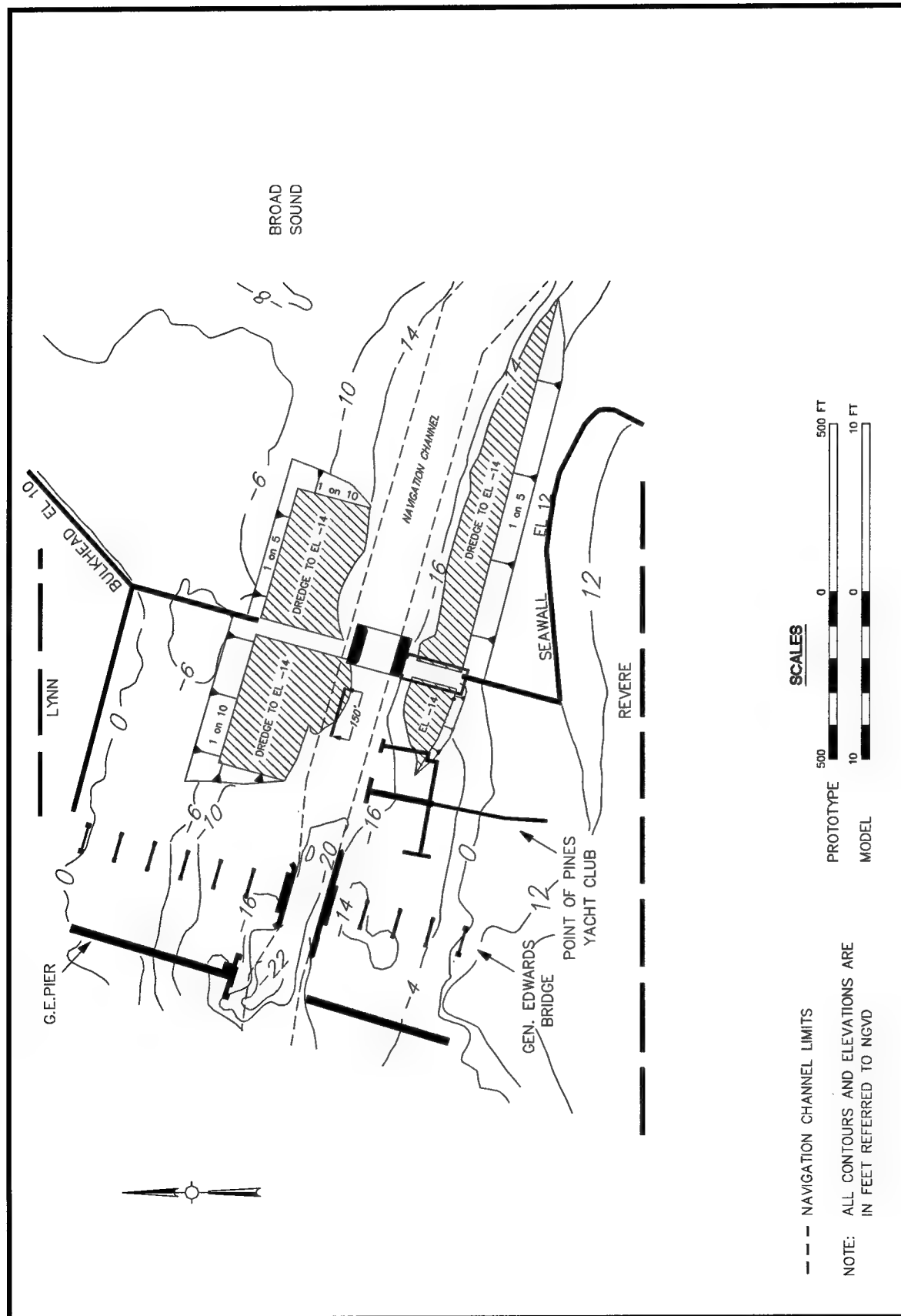


Figure 11. Plan 2C, bottom gate el +7, Alternative 2, Stage 2 construction

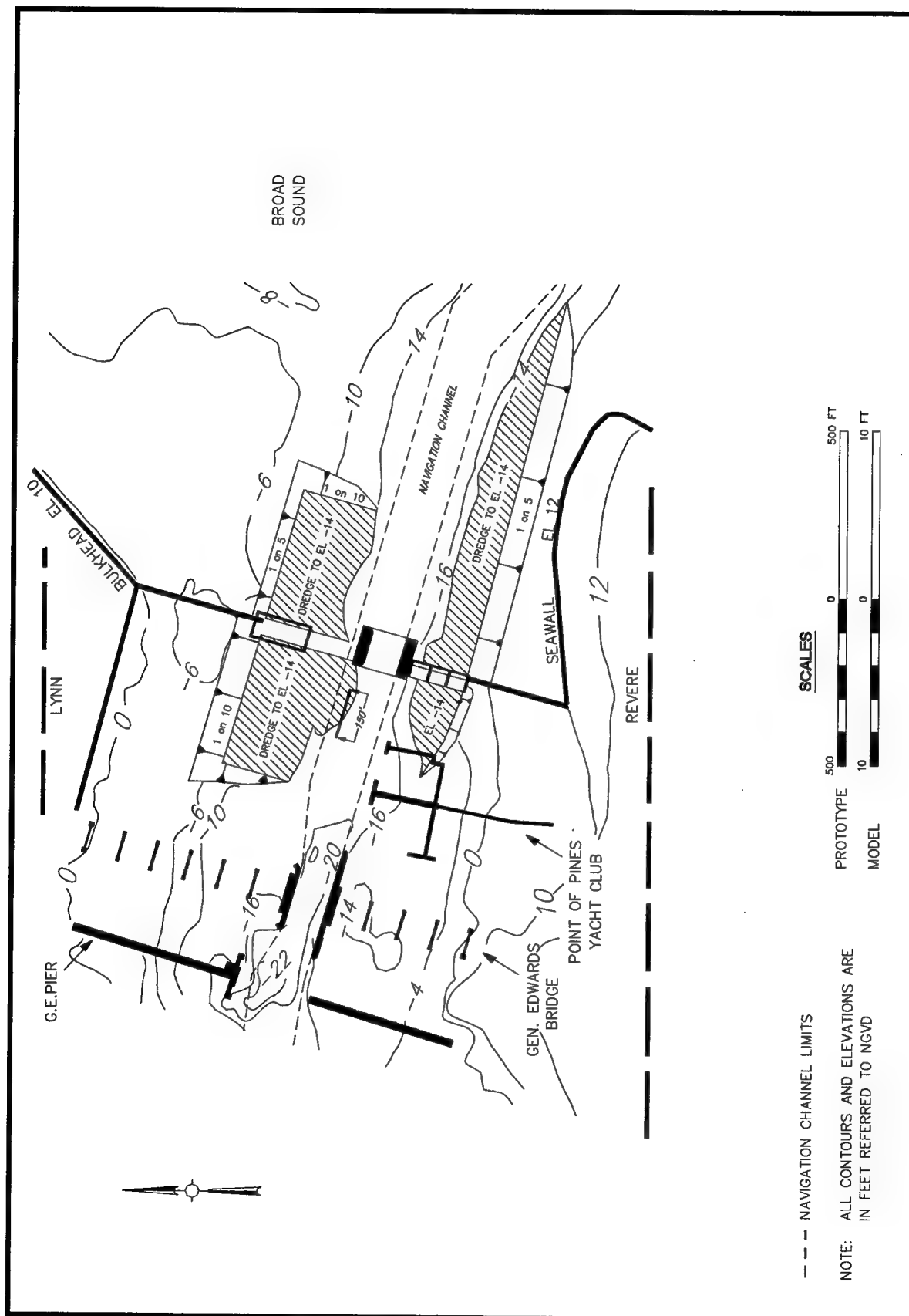


Figure 12. Plan 2C, bottom gate el +7, Alternative 2, Stage 3 construction

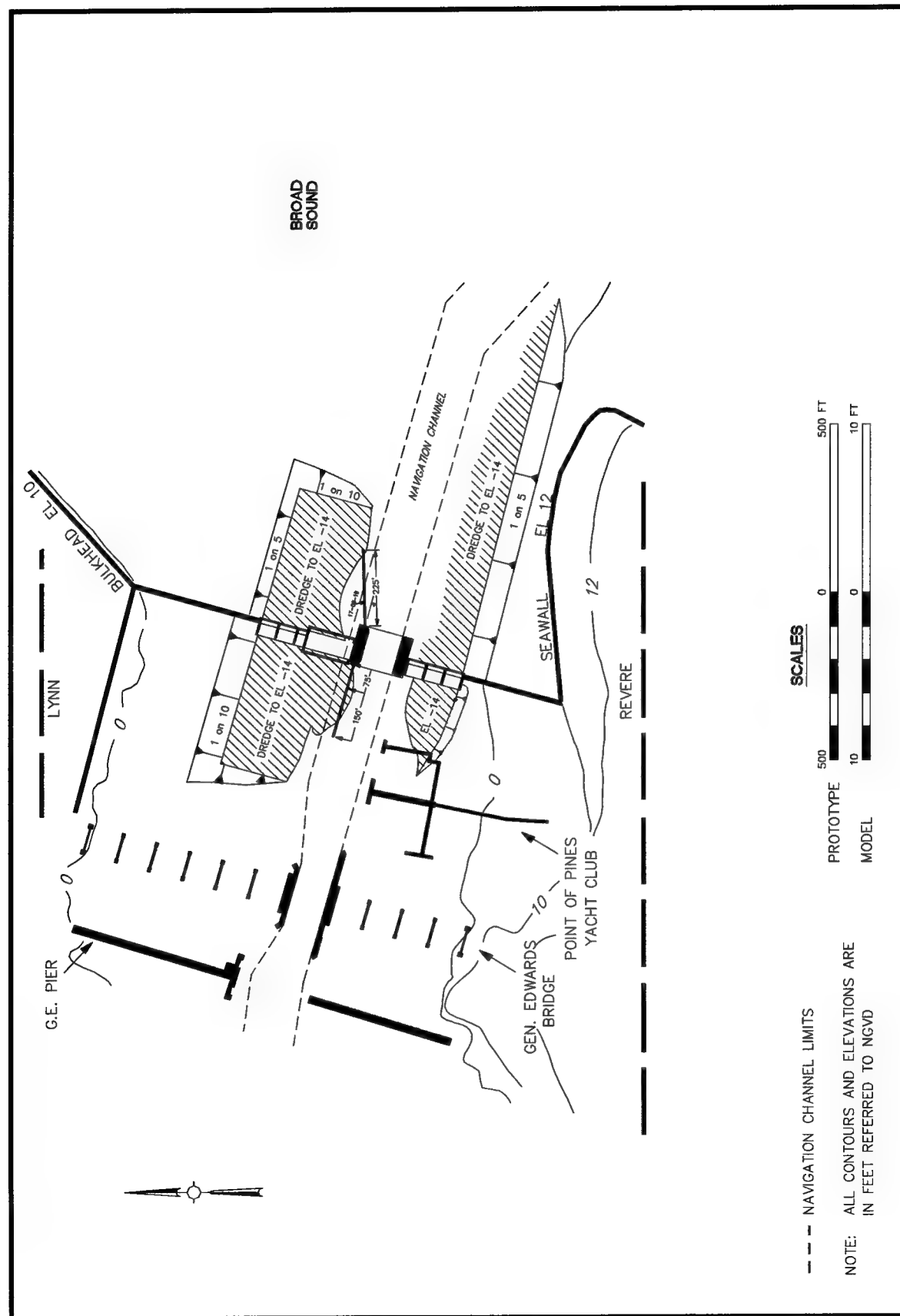


Figure 13. Plan 2C, bottom gate el +7, Alternative 2, Stage 4 construction

along the south shore. Three gates (gates 6, 7, and 8) would be constructed during Stage 2.

- c. Stage 3, shown in Figure 12, would require construction of a square cofferdam and would allow construction of the northernmost two and one half tainter gates (gates 1, 2, and half of 3).
- d. Stage 4, shown in Figure 13, would require construction of a square cofferdam and would allow construction of the remainder of the tainter gates on the north side (remaining half of gate 3 and gates 4 and 5). Also, the splitter wall on the inland side of the structure would have to be extended to the north pier of the navigation gate. This would require an additional 75 ft of wall to make the connection. Another splitter wall would be constructed on the sound side of the project. The sound-side splitter wall will be 225 ft long and rotated counterclockwise about 17 deg off the center line of the northern pier of the navigation gate.

Since Alternative 2 is the most likely construction sequence to be followed, point velocity measurements were taken in the vicinity of the construction area near the cofferdams. The velocities were taken to provide guidance for the design of scour protection during construction. These data are presented in Appendix C. Also included in Appendix C are swellhead measurements across the cofferdams for all phases of construction.

Results

Current direction and velocities, Stage 1. Current direction and velocity data are shown in Plates 52-55. With flood flow (Plates 52 and 53), current magnitudes approaching the cofferdam ranged from about 1.0 to 2.0 fps with the neap and spring tides, respectively. As the flow approached the constrictions between the cofferdam and the gravity walls, the currents increased to about 2.5 fps with the neap tide and to about 5.5 fps with the spring tide. These data also indicate that these high current magnitudes tended to remain high as far inland as the GEB. It should be noted that the flow downstream of the cofferdam was very unsteady. The splitter wall on the downstream side tends to reduce the unsteady flow in this area. Current direction and velocity data indicate that most of the flow moving around the cofferdam did not tend to move through the navigation span of the GEB. It appears that only a portion of the flow moving around the north side of the cofferdam moved through the navigation span of the GEB. The maximum current magnitude recorded in the navigation span of the GEB ranged from about 2.0 fps to 5.5 fps with neap and spring tides, respectively. A large clockwise eddy was observed along the north shore between the GEB and flood-control structure with both the neap and spring tides.

With ebb flow (Plates 54 and 55), the maximum current magnitudes in the navigation span of the GEB ranged from about 1.5 to 2.8 fps with the neap and spring tides, respectively. As the flow moved through the constriction at the cofferdam, current magnitudes increased. The maximum current magnitudes

recorded in this area ranged from about 2.6 fps to 5.0 fps with the neap and spring tides, respectively. As was noted with flood flow, the flow downstream of the cofferdam was unsteady. A large clockwise eddy was observed along the south shore seaward of the cofferdam. The flow moving past the cofferdam toward Broad Sound appeared to remain concentrated toward the navigation channel for some distance seaward. The flow in this area was also unsteady. The maximum current magnitudes downstream of the cofferdam ranged from about 2.0 to 4.4 fps with the neap and spring tides, respectively.

Navigation conditions, stage 1. Navigation conditions are shown in Plates 56-63. With flood flow, navigation conditions were satisfactory for marginally powered small craft, but not without some difficulties. With Stage 1 construction, traffic is required to pass the construction area on the north side of the cofferdam. Inbound traffic could approach the construction area and move past the cofferdam with no significant difficulties. However, navigation difficulties were encountered while the small vessels were attempting to move from the north side of the cofferdam across the flow and into the navigation span of the GEB (Plates 56 and 57). Inbound traffic experienced a strong tendency to be pushed toward the south side fender of the GEB by the flow in this area. The most difficulty was experienced with the spring tide. The cofferdam splitter wall reduced the unsteady flow conditions and streamlined the flow. It cannot be overemphasized that navigation conditions were evaluated for marginally powered vessels. Some of the navigation difficulties could be overcome with additional power. Navigation conditions were satisfactory for outbound traffic (Plates 58 and 59). Outbound traffic could exit the navigation span of the GEB, align with the flow, navigate past the cofferdam on the north side, and proceed toward Broad Sound.

With ebb flow and Stage 1 construction, navigation conditions were satisfactory for both outbound and inbound traffic (Plates 60-63). Outbound traffic could pass through the navigation span of the GEB, move past the construction area, and toward Broad Sound with no significant difficulties (Plates 60 and 61). However, with the spring tide, there was a tendency for outbound traffic to encroach on the first stage splitter wall (Plate 61). Inbound traffic could align with the flow, approach and move past the cofferdam, and align with and move through the navigation span of the GEB with no significant difficulties (Plates 62 and 63).

Current direction and velocities, stage 2. Current direction and velocity data flood and ebb flow are shown in Plates 64-67. With flood flow (Plates 64 and 65), current magnitudes in the Broad Sound area generally ranged from about 1.0 to 2.0 fps with the neap and spring tides, respectively. The current magnitudes increased at the construction site to about 2.0 fps with the neap tide and 5.3 fps with the spring tide. In general, the highest current magnitude tended to occur in the newly constructed navigation gate. In general, the flow appeared to move parallel with the navigation channel through the navigation gate of the flood-control structure to a point about 100 ft from the south side bridge fender of the GEB, and then toward or to the south of the south bridge fender. The maximum current magnitude observed in the navigation span of the GEB ranged

from about 1.7 to 3.9 fps with the neap and spring tides, respectively. With flood flow, a large counterclockwise eddy was observed in the vicinity of the PPYC with both the neap and spring tides. The maximum upstream current magnitude in the eddy ranged from about 0.5 to 1.4 fps with the neap and spring tides, respectively.

With ebb flow (Plates 66 and 67), current magnitudes in the navigation span of the GEB ranged from about 1.7 to 2.8 fps with the neap and spring tides, respectively. The flow approaching the navigation gate appeared to move slightly toward the north with both the neap and spring tides. The maximum current magnitude recorded in the navigation channel approaching the navigation gate was 1.5 to 2.4 fps with the neap and spring tides, respectively. The maximum velocity recorded on the north side of the navigation gate was 1.9 fps with the neap tide and 4.2 fps with the spring tide. The maximum velocity in the Broad Sound area ranged from about 1.7 fps to 3.4 fps with the neap and spring tides, respectively. With both the neap and spring tides, a large clockwise eddy was observed on the south shore seaward of the flood-control structure. The maximum upstream velocity recorded ranged from about 0.7 to 1.5 fps with the neap and spring tides, respectively.

Navigation conditions, Stage 2. Navigation conditions are shown in Plates 68-77. Navigation conditions were satisfactory with all conditions tested for both inbound and outbound traffic. With flood flow and the neap and spring tides, inbound and outbound traffic could pass either on the north side of the navigation gate or through the navigation gate with no significant difficulties (Plates 68-71). With the spring tide and flood flow, inbound traffic tended to move toward the south side bridge fender of the GEB (Plate 69). Outbound traffic could align with the flow and proceed seaward with no significant difficulties.

With ebb flow, navigation conditions were satisfactory with the neap and spring tides for both inbound and outbound traffic (Plates 72-77). Inbound and outbound traffic could navigate either through the navigation gate or on the north side of the navigation gate. With the spring tide, navigation conditions were a little more difficult than those observed with the neap tide due to higher velocities. As shown in Plate 73, outbound traffic navigating past the navigation gate to the north experienced a tendency to encroach on the splitter wall between the GEB and the navigation gate. Inbound traffic experienced no significant difficulties navigating through the navigation gate or to the north of the navigation gate.

Current directions and velocities, Stage 3. Current direction and velocity data are shown in Plates 78-81. With flood flow (Plates 78 and 79), current magnitudes in the Broad Sound area ranged from about 1.0 to 1.7 fps with the neap and spring tides, respectively. As the flow moved closer to the structure, a crosscurrent developed across the navigation channel and current magnitudes increased. At the structure, current magnitudes in the navigation gate ranged from about 2.0 to 4.7 fps with the neap and spring tides, respectively. As the flow passed through the structure, it moved more or less parallel to the

navigation channel and tended to remain parallel to the point where it split around the south side bridge fender of the GEB. The maximum current magnitude recorded in the navigation span of the GEB ranged from about 1.8 to 3.9 fps with the neap and spring tides, respectively. A large clockwise eddy was observed along the north shore between the GEB and the flood-control structure. The maximum upstream velocity recorded ranged from less than 0.5 fps with the neap tide to 0.7 fps with the spring tide.

With ebb flow (Plates 80 and 81), the flow moved through the navigation span of the GEB more or less parallel to the navigation channel to about the splitter wall where a crosscurrent moving from north to south developed. The maximum velocity recorded in the navigation span of the GEB ranged from about 1.7 to 2.7 fps with the neap and spring tides, respectively. The maximum velocity recorded in the navigation gate ranged from about 2.0 to 3.4 fps with the neap and spring tides, respectively. As the flow moves on into the Broad Sound area, current magnitudes decreased to about 1.1 fps with the neap tide and to about 2.5 fps with the spring tide.

Navigation conditions, Stage 3. Navigation conditions are shown in Plates 82-89. Navigation conditions were satisfactory for both inbound and outbound traffic with all conditions tested. With Stage 3 construction, traffic was required to pass through the navigation gate, unlike Stage 2 where traffic could either go through the navigation gate or to the north side of the navigation gate. With flood flow (Plates 82 and 83), inbound traffic could approach the navigation gate from Broad Sound in about the middle of the navigation channel with no significant difficulties. However, as the boat approached the GEB, a crosscurrent developed in the navigation channel that tended to move the vessel toward the south shore and out of alignment with the navigation gate. Inbound traffic did appear to encroach on the south pier of the navigation gate especially with the spring tide (Plate 83). Once clear of the navigation gate, inbound traffic could align with the navigation span of the GEB and proceed inland with no significant difficulties. Navigation conditions were satisfactory for outbound traffic (Plates 84 and 85). Navigation conditions were a little more difficult with the spring tide than with the neap tide, because of higher velocity currents.

With ebb flow (Plates 86-89), navigation conditions were satisfactory for both inbound and outbound traffic. Outbound traffic could pass through the GEB, align with and pass through the navigation gate, and proceed seaward with no significant difficulties. The crosscurrent approaching the navigation gate tended to move the vessel somewhat out of alignment with the navigation gate, especially with the spring tide (Plate 87). However, it did not cause any significant difficulties for outbound traffic. Navigation conditions were satisfactory for inbound traffic (Plates 88 and 89). Inbound traffic could align with the flow and move inland from Broad Sound with no significant difficulties.

Current directions and velocities, Stage 4. Current direction and velocity data are shown in Plates 90-93. With flood flow (Plates 90 and 91), current magnitudes in Broad Sound approaching the flood-control structure ranged from about 1.2 fps with neap tide to about 1.9 fps with the spring tide. As the flow

moved farther inland, a crosscurrent developed across the navigation channel and current magnitudes increased. The splitter wall on the sea side of the navigation gate tended to aid in "funneling" the flow into the navigation gate. In the vicinity of the navigation gate, current magnitudes ranged from about 2.0 to 4.5 fps with the neap and spring tides, respectively. The flow moved generally parallel to the navigation channel between the navigation gate and GEB to about the end of the south bridge fender of the GEB. The maximum current magnitude recorded in the navigation span of the GEB ranged from about 1.7 fps with the neap tide to about 3.5 fps with the spring tide. A large clockwise eddy was observed along the north shore and a counterclockwise eddy on the downstream side of the Stage 4 cofferdam with the neap and spring tides. As noted before, the flow on the downstream side of the cofferdam was very unsteady. The west splitter wall assisted in keeping this eddy out of the navigation channel. A smaller eddy was also observed near the PPYC with the spring tide.

With ebb flow (Plates 92 and 93), current direction and velocity data indicated that the flow moved through the navigation span of the GEB and more or less parallel to the navigation channel to about the end of the splitter wall. The flow then tended to move toward the south and back into the navigation gate. This tendency was more noticeable with the spring tide. Maximum current magnitudes recorded in the navigation span of the GEB ranged from about 1.6 to 3.0 fps with the neap and spring tides, respectively. The maximum current magnitudes recorded in the navigation gate ranged from about 2.2 fps with the neap tide to about 4.1 fps with the spring tide. As the flow exited the navigation gate, most of the flow moved parallel to the navigation channel. However, some of the flow began to move to the north. As noted before, the flow on the downstream side of the cofferdam was unsteady. The maximum current magnitude recorded in the navigation channel in the Broad Sound area ranged from about 1.4 to 3.4 fps with the neap and spring tides, respectively.

Navigation conditions, Stage 4. Navigation conditions are shown in Plates 94-101. With flood flow, navigation conditions were satisfactory for both inbound and outbound traffic with the neap and spring tides. Inbound traffic could align with and pass through the navigation gate with no significant difficulties (Plates 94 and 95). Once past the navigation gate, inbound vessels could align with the navigation span of the GEB, pass through the GEB, and proceed inland. Inbound traffic experienced some difficulties at the entrance to the GEB. The flow in this area tended to move the vessels toward the north side of the GEB. The flow was more unsteady with the spring tide. Navigation conditions were satisfactory for outbound traffic (Plates 96 and 97). Outbound traffic experienced some difficulties between the GEB and the navigation gate due to the current patterns in this area; again, this is more noticeable with the spring tide.

With ebb flow, navigation conditions were satisfactory for outbound traffic (Plates 98 and 99). However, a fairly strong crosscurrent developed in the navigation channel near the PPYC that tended to move vessels toward the south shore and out of alignment with the navigation gate. This did not appear to have significant impacts on outbound vessels since the flow immediately returned to

the navigation channel and through the navigation gate. Navigation conditions were satisfactory for inbound traffic (Plates 100 and 101). Inbound vessels could align with the flow and move from Broad Sound inland with no significant difficulties.

Alternative 1

Description

Construction sequence Alternative 1 (CSA 1) is shown in Figures 14-17. CSA 1 is the same as CSA 2 with a few exceptions:

- a. Stage 1 construction, shown in Figure 14, is the same as CSA 2 except that the gravity walls on the north and south shores would not be constructed concurrently with the Stage 1 cofferdam.
- b. Stage 2 construction, shown in Figure 15, is the same as CSA 2 except that the south shore gravity wall would be constructed concurrently with the Stage 2 cofferdam and the north gravity wall would not be present.
- c. Stage 3 construction, shown in Figure 16, is the same as CSA 2 except that the north shore gravity wall would be constructed concurrently with the Stage 3 cofferdam.
- d. Stage 4 construction, shown in Figure 17, is the same as CSA 2.

Discussion

Although conditions were not fully documented for this construction sequence, some very good conclusions could be drawn from the test results of CSA 2. Since the gravity walls would not be constructed during the Stage 1 construction, it would be safe to assume that current magnitudes in the vicinity of the structure would be reduced due to the increase in cross-sectional area compared with those of CSA 2. Flow patterns may change slightly, but the changes are probably not significant enough to have adverse impacts on navigation. Since the current magnitudes are reduced, then navigation conditions generally can be expected to be better during CSA 1 than those observed with CSA 2.

The same situation would occur for Stage 2 construction of CSA 1. With Stage 2 of CSA 1, the north shore gravity wall would not be in place; therefore, current magnitudes should decrease because of the increase in cross-sectional area compared with that of CSA 2. And since current magnitudes are less for CSA 1, navigation conditions should be better than those observed with CSA 2.

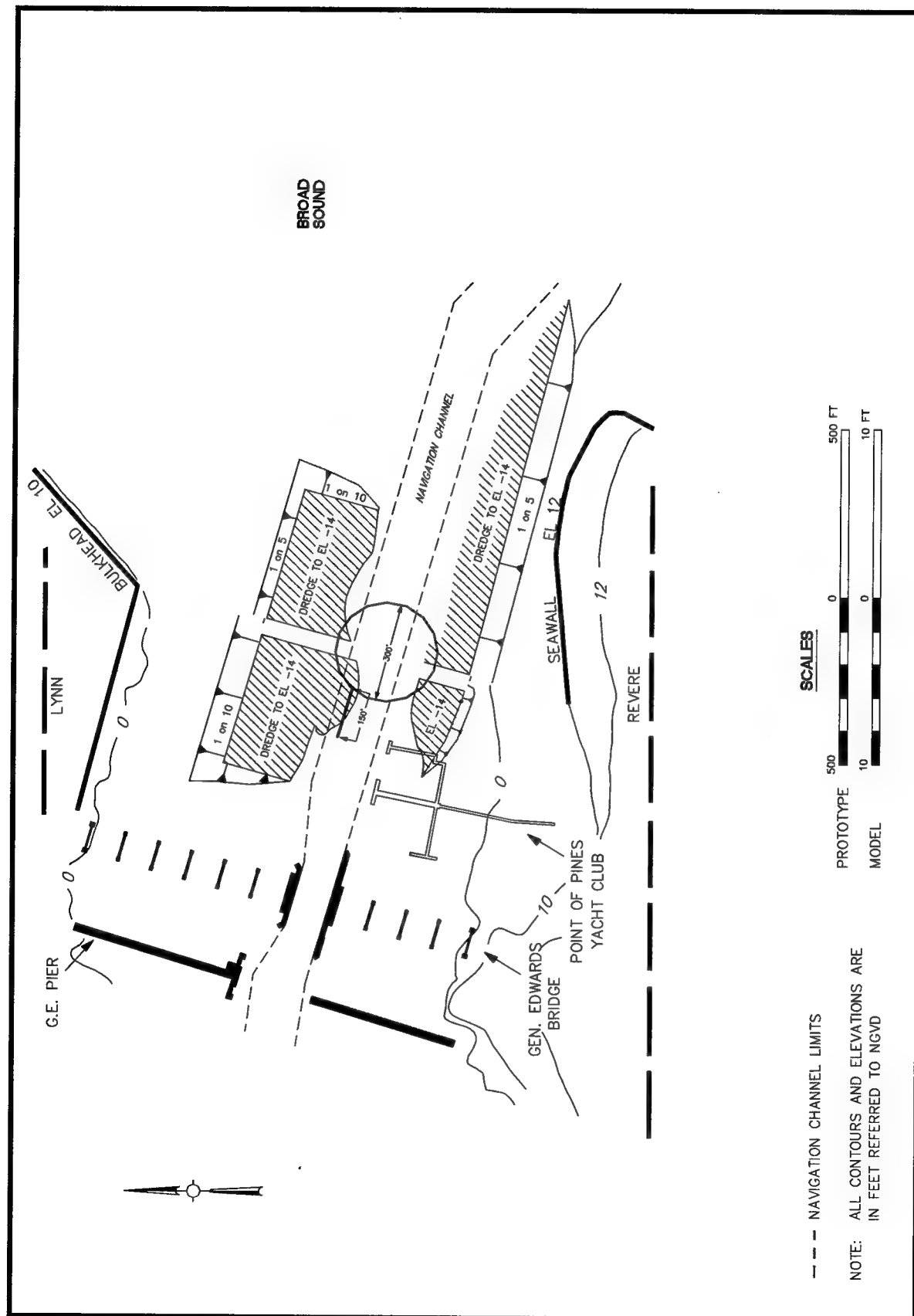


Figure 14. Plan 2C, bottom gate el +7, Alternative 1, Stage 1 construction

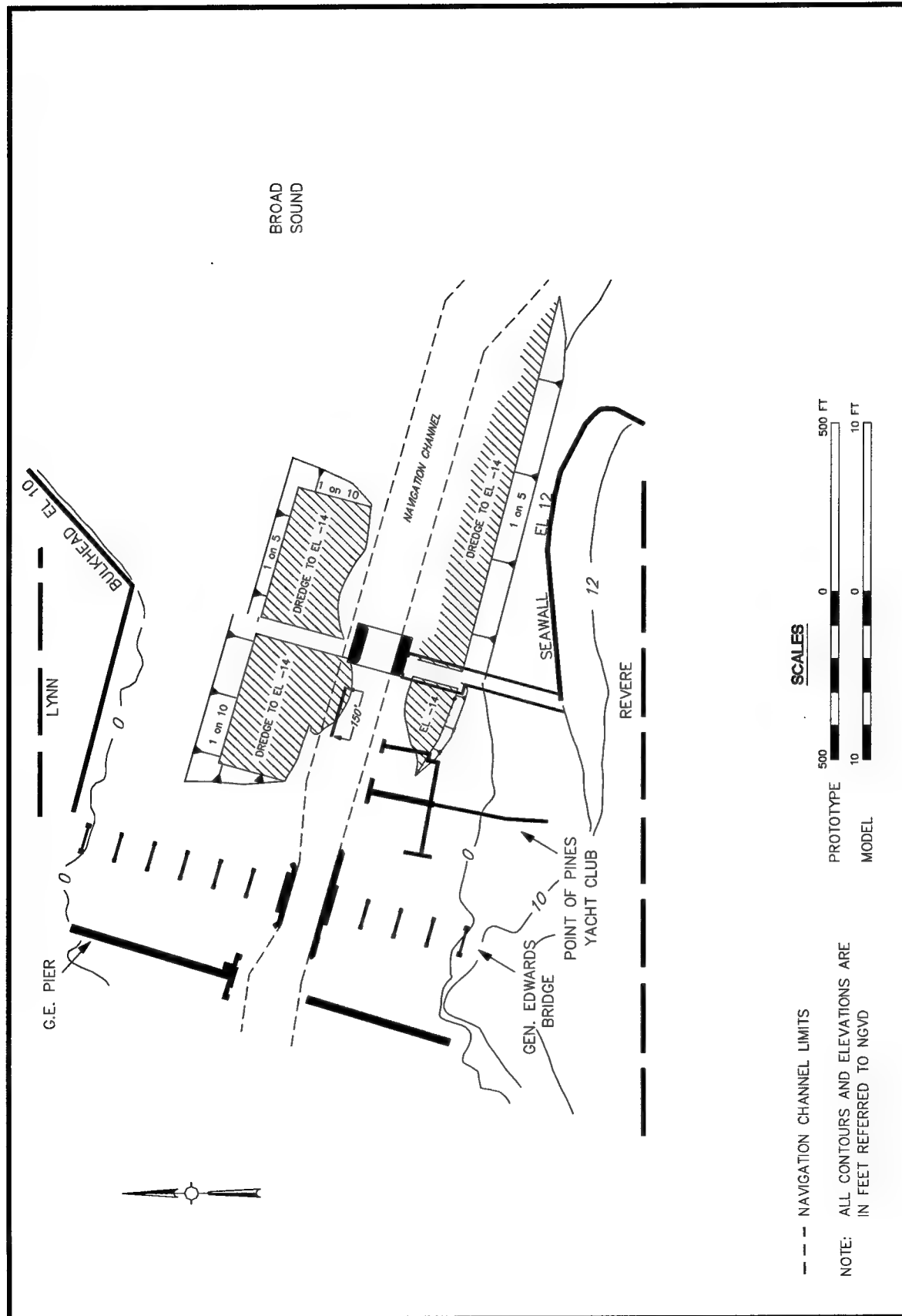


Figure 15. Plan 2C, bottom gate el +7, Alternative 1, Stage 2 construction

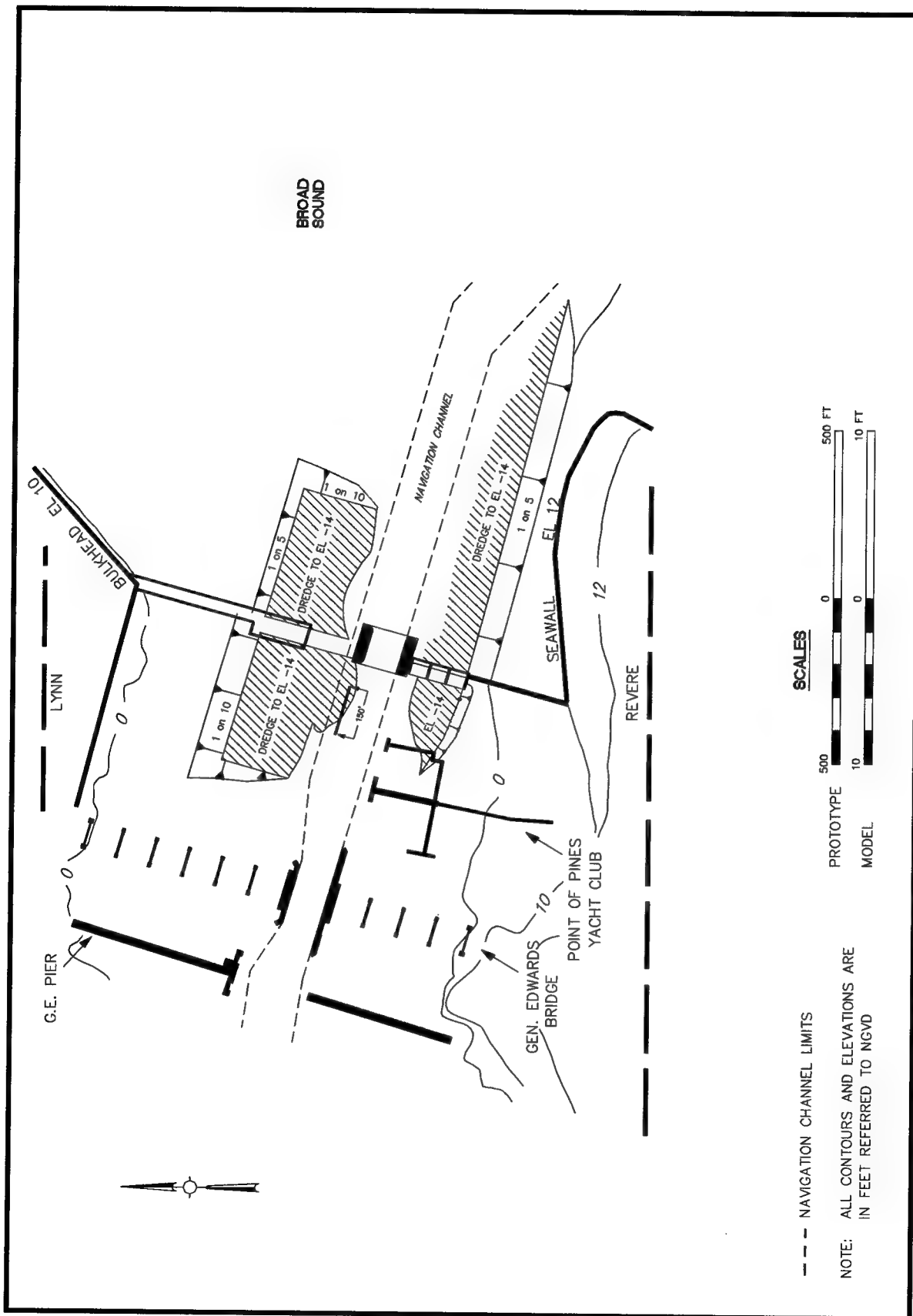


Figure 16. Plan 2C, bottom gate el +7, Alternative 1, Stage 3 construction

Current magnitudes and directions and navigation conditions for Stages 3 and 4 of CSA 1 should not be significantly different from those observed with CSA 2.

Alternative 3

Description

As mentioned previously, construction sequence Alternative 3 (CSA 3), is a different construction scheme from Alternatives 1 and 2. CSA 3, shown in Figures 18-20, would require building the flood-control structure in three stages from the Lynn shore (north shore) to the Revere shore (south shore). A description of each stage of construction follows:

- a. Stage 1 construction, shown in Figure 18, would require construction of a rectangular type cofferdam that would allow construction of the north shore gravity wall and almost all of the five tainter gates on the north side of the navigation gate.
- b. Stage 2 construction, shown in Figure 19, would require construction of a 300-ft-diam circular cofferdam that would allow construction of the navigation gate, the remaining portion of tainter gate 5, and a portion of tainter gate 6 (first gate south of the navigation gate). A portion of the PPYC would be removed from the east side to provide clearance between the PPYC and the cofferdam. Also, three dikes with top elevation about +8.0 and about 65 ft in length were placed near the PPYC.
- c. Stage 3 construction, shown in Figure 20, would require construction of a rectangular type cofferdam that would allow construction of the remainder of the tainter gates (6, 7, and 8) along the south shore and the south shore gravity wall.

Results

This alternative was observed and evaluated on the model for all three stages of construction. Current direction and velocity data and vessel tracks were recorded for Stage 2 only, since navigation conditions were unsatisfactory for Stage 2.

Current direction and velocities, Stage 2. Current direction and velocity data for the spring tide are shown in Plates 102 and 103. With flood flow (Plate 102), traffic was required to pass the construction area along the south shore. For the purpose of this evaluation, the primary focus will be on the flow patterns developed along the south shore. Maximum current magnitudes recorded along the south shore in the Broad Sound area ranged from about 1.0 to 1.4 fps. As the flow moved closer to the cofferdam, current magnitudes

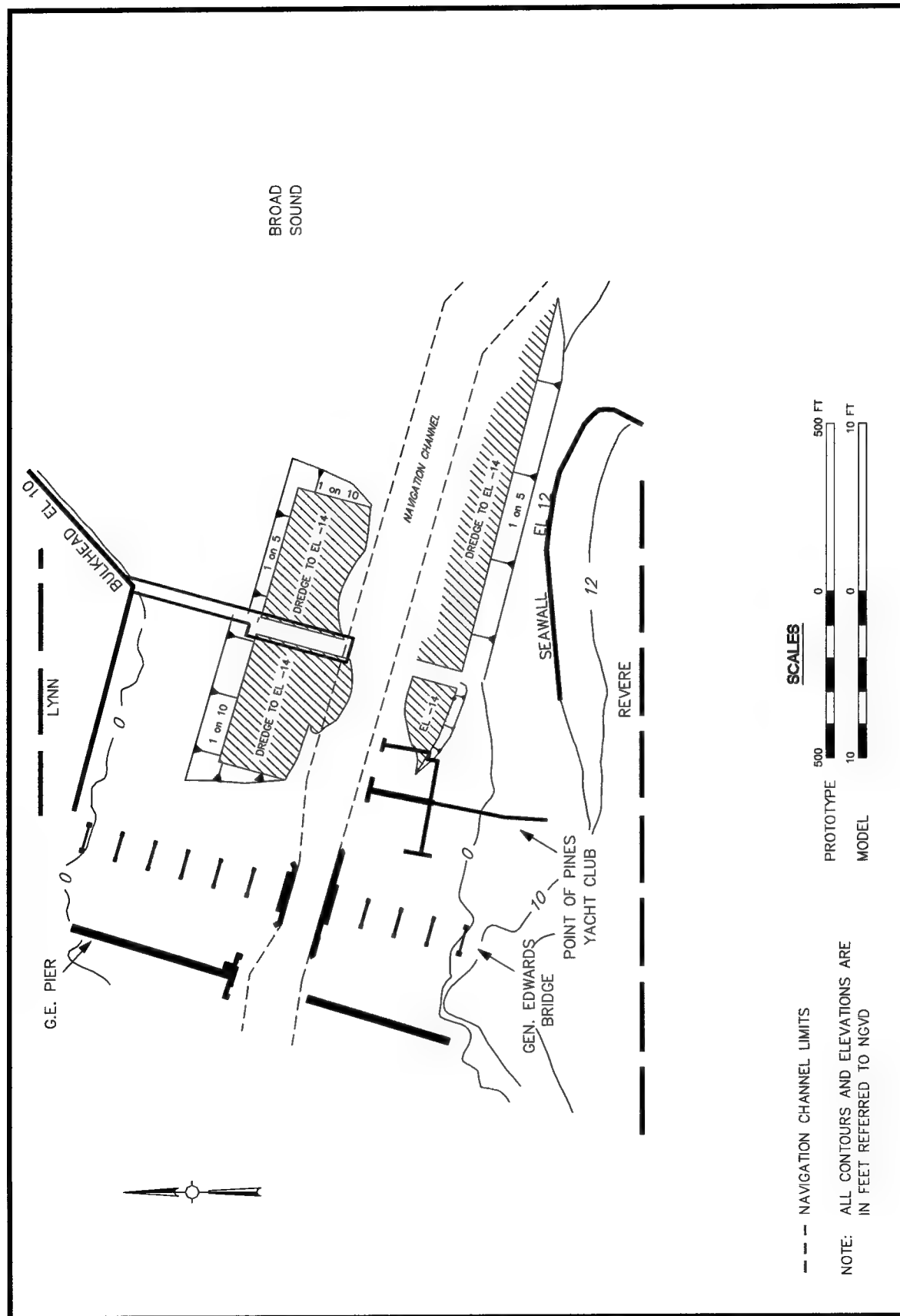


Figure 18. Plan 2C, bottom gate el +7, Alternative 3, Stage 1 construction

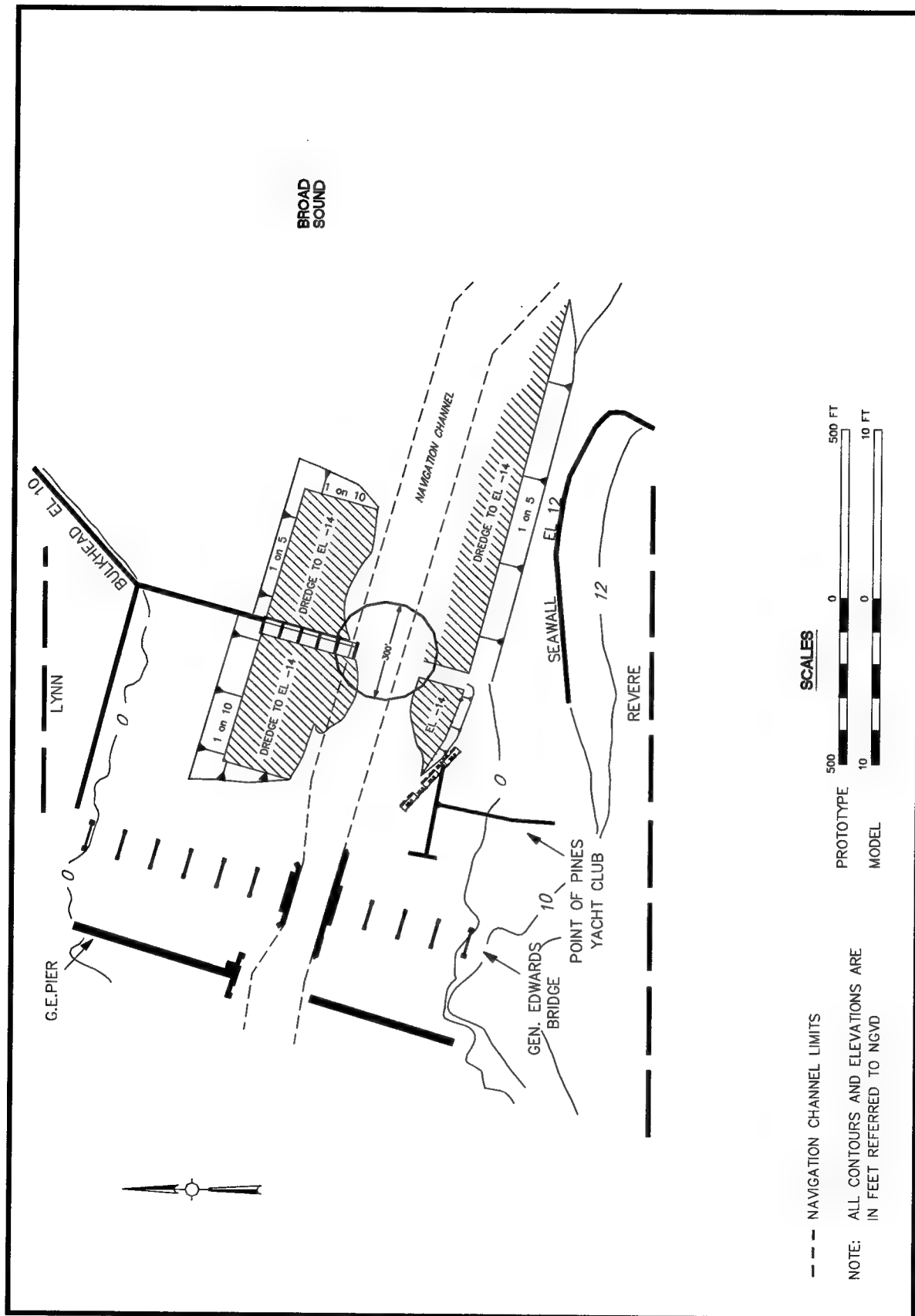


Figure 19. Plan 2C, bottom gate el +7, Alternative 3, Stage 2 construction

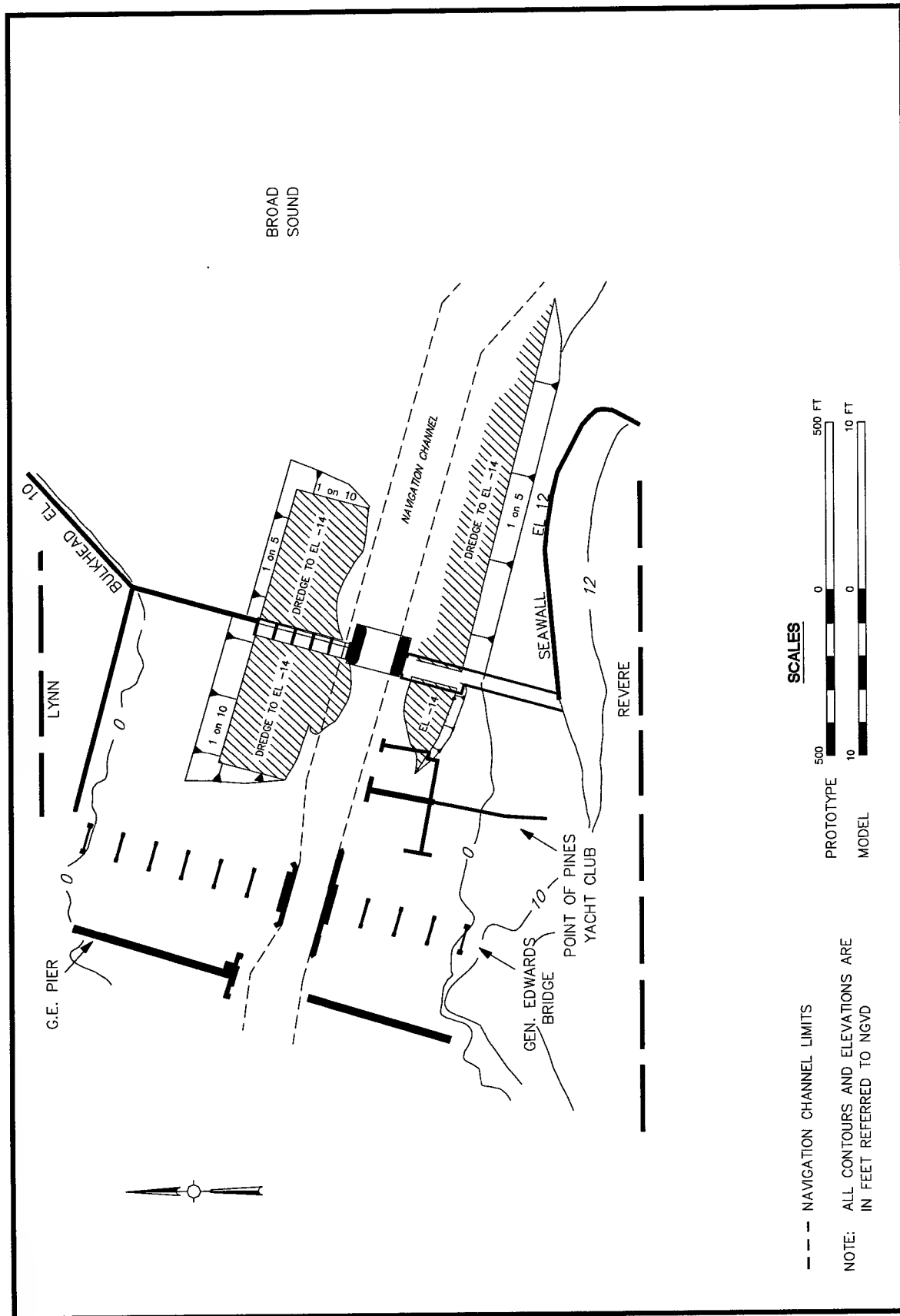


Figure 20. Plan 2C, bottom gate el +7, Alternative 3, Stage 3 construction

increased to a maximum of about 5.1 fps at the constriction. The flow moved inland to the dikes and then began to move toward the navigation span of the GEB. However, it appears that most of the flow moved through the bridge span to the south of the navigation span of the GEB. The maximum current magnitude recorded in this area was about 5.5 fps. The maximum current magnitude recorded in the navigation span of the GEB was about 3.9 fps. As noted with all other tests, the flow on the downstream side of the cofferdam was very unsteady. The eddy on the downstream side of the cofferdam pulsated. The flow on the downstream side of the dikes was also unsteady.

With ebb flow (Plate 103), the flow generally moved parallel through the GEB with maximum current magnitude in the navigation span of about 2.5 fps. The flow moved seaward and then split around the cofferdam. The maximum current magnitude at the constriction was about 6.2 fps. Again, the flow on the downstream side of the cofferdam was very unsteady. The maximum current magnitude along the south shore seaward of the cofferdam ranged from about 6.0 fps to about 2.0 fps.

Navigation conditions, Stage 2. Navigation conditions are shown in Plates 104-107. With flood flow, navigation conditions were unsatisfactory for inbound traffic with the spring tide (Plate 104). Inbound traffic could approach and pass the construction area from Broad Sound with no significant difficulties. However, after passing the cofferdam, inbound traffic was required to maneuver across the high-velocity currents to align with the navigation span of the GEB. The current directions and velocities in this area quite often resulted in the lobster boat striking the south bridge fender of the GEB, being forced through the bridge span just to the south of the navigation span, or getting caught in the eddy on the downstream side of the cofferdam. For outbound traffic (Plate 105), navigation conditions were difficult due mainly to the unsteady and high-velocity currents in the vicinity of the PPYC and the GEB. However, once clear of this area, outbound traffic could align with the incoming flow and proceed seaward with no significant difficulties.

With ebb flow, navigation conditions were satisfactory for outbound and inbound movements (Plates 106 and 107). Outbound traffic could align with and pass through the navigation span of the GEB, pass the construction area on the south shore, and proceed seaward with no significant difficulties (Plate 106). Inbound traffic experienced some difficulties approaching the construction area due to unsteady currents seaward of the cofferdam. Once past this area, inbound traffic could align with the flow and pass through the navigation span of the GEB with no significant difficulties (Plate 107).

Tainter Gate Bulkhead Tests

Bulkhead tests were performed with spring tide conditions and the CSA 2 construction sequence. Current direction and velocity data were not collected with these tests. The remote-controlled lobster boat, confetti, and dye were used

to observe and evaluate the current patterns that would develop and describe the effects on navigation through the study reach. The remote- controlled lobster boat was operated to represent vessels of marginal power.

Stage 3 Construction

With Stage 3 construction, the flushing gates along the south shore, gates 6-8, would be closed with bulkheads at some time during construction of the northern two and one-half flushing gates to allow for the physical installation of the tainter gate. Model results indicated that no more than one flushing gate should be closed with bulkheads during Stage 3 construction. The model also indicated that closing flushing gate 6 with bulkheads would cause adverse impacts to navigation, particularly with flood flow. With flushing gate 6 bulkheaded, current patterns were very erratic and pulsating between the GEB and the floodgate structure. Navigation conditions for inbound traffic were very difficult due to the nature of the flow in this area. Approach conditions from Broad Sound were satisfactory; however, once past the navigation gate of floodgate structure, inbound traffic could encounter a variety of unsteady flow patterns, which are difficult to adjust and correct for. Due to the navigation conditions observed with flushing gate 6 closed with bulkheads, the tainter gate for flushing gate 6 should be installed while the Stage 2 cofferdam is in place.

With ebb flow and flushing gate 6 closed with bulkheads, the erratic and pulsating currents were also evident on the seaward side of the floodgate structure. However, since there were no structures that outbound traffic was required to maneuver past, the impacts on navigation conditions were not as critical as those observed with flood flow.

With both ebb and flood flow, navigation conditions were more difficult for inbound and outbound traffic than for those observed with normal Stage 3 construction.

Navigation conditions were satisfactory for inbound and outbound traffic with both flood and ebb flow when flushing gate 7 or 8 was closed with bulkheads. However, flushing gates 7 and 8 should not be closed with bulkheads at the same time. The flow near the floodgate structure was more erratic with these gates bulkheaded, but did not cause any significant adverse impacts to navigation conditions in the area.

Conditions were also observed with flushing gates 6, 7, and 8 closed and gates 7 and 8 closed at the same time. Navigation conditions were not satisfactory with either of these conditions. Current magnitudes were significantly increased and flow patterns were more erratic than those observed with normal Stage 3 construction.

Stage 4 Construction

With flushing gate 1 or 2 closed with bulkheads, navigation conditions were satisfactory for inbound and outbound traffic with flood flow. However, the crosscurrent approaching the navigation gate seaward of the floodgate structure increased in both magnitude and direction compared with that of normal Stage 4 construction.

With ebb flow and flushing gate 1 or 2 closed with bulkheads, navigation conditions were satisfactory but difficult for outbound traffic, particularly for marginally powered vessels. When the flow capacity of the floodgate structure was reduced, the crosscurrent between the GEB and the navigation gate increased in magnitude and direction, particularly near the end of the splitter wall. Particular caution should be taken by underpowered outbound traffic in this area. It should be noted that vessels with more power and steering capabilities could very likely overcome any difficulties that could be encountered for these conditions.

Navigation conditions were satisfactory for inbound traffic with flushing gate 1 or 2 closed with bulkheads. The increase in the crosscurrent between the GEB and the navigation gate did cause more difficulties for inbound traffic compared with those observed with normal Stage 4 construction.

Navigation conditions were not satisfactory with ebb or flood flow with flushing gates 1 and 2 closed with bulkheads at the same time. The crosscurrents approaching the navigation gate were considered excessive and could cause significant difficulties for inbound and outbound traffic moving through the construction area.

Semi-Postproject Results

With flushing gates 4 and 5 closed with bulkheads at the same time, navigation conditions were satisfactory for inbound and outbound traffic with flood and ebb flow. This is provided that the splitter walls developed for Stage 4 construction remain in place at least until installation of tainter gates 4 and 5 is completed. Navigation conditions were very similar to those observed with the normal Stage 4 construction.

After the tainter gates are installed for flushing gates 4 and 5, the splitter wall can be removed and flushing gate 3 could be closed with bulkheads. Navigation conditions were satisfactory for inbound and outbound traffic with ebb and flood flow.

4 Discussion of Results and Conclusions

Limitations of Model Results

Analysis of the results of this investigation is based on a study of current directions and velocities and the effect of the resulting currents on the behavior of the model tanker and lobster boat. An evaluation of test results should consider that small changes in current direction and velocities are not necessarily changes produced by a particular modification, since several floats introduced at the same point may follow a different path and move at a slightly different velocity because of eddies and pulsating currents. The current directions and velocities shown in the plates were taken with floats submerged to the depth of 4 ft and are indicative of the currents that would affect the behavior of the model tanker and lobster boat.

Because of the model scale, prototype current directions and velocities could be somewhat different from model current directions and velocities, since flow in the prototype varies with time (tidal influence) and the model data were based on steady flow conditions. The flow conditions selected for testing produced maximum currents expected to be experienced by navigation during the tide cycle. The model was of the fixed-bed type and was not designed to reproduce overall sediment movement that might occur in the prototype with the various alternatives tested. Thus, changes in the channel configuration resulting from scouring and deposition and any resulting changes in current directions and velocities were not directly evaluated.

Summary of Results and Conclusions

The following results and conclusions were developed during the model study:

Existing conditions

These tests produced the following results:

- a.* With a slack tide, navigation conditions were satisfactory for inbound and outbound tankers.
- b.* With the neap tide, navigation conditions were difficult for both inbound and outbound tankers with flow moving in both the ebb and flood directions. Conditions were difficult because of irregularities in currents in the navigation channel and through the navigation span of the General Edwards Bridge and the short distances over which the tanker encountered changes in current direction, structures, and the channel bends.
- c.* With the spring tide, navigation conditions were very much the same as with the neap tide, but were increasingly difficult because of higher discharges in both the ebb and flood direction.
- d.* Although velocities are relatively low in magnitude (1.5 knots or less), with all the structural features that exist in such close proximity and the irregularities in the current patterns in the navigation channel, the tanker would most likely wait until a slack period in the tide to either deliver the jet fuel to the G.E. plant or leave the G.E. plant in ballast.

Base conditions, breaching of the I-95 embankment

- a.* These tests indicated some changes in current patterns and velocities compared with those observed with existing conditions and in particular with the spring tide and ebb flow. Velocities were increased, and the crosscurrents at the confluence of the Pines and Saugus Rivers were stronger than those observed with existing conditions.
- b.* Navigation conditions for inbound and outbound tankers were about the same as those observed with existing conditions. With the spring tide and ebb flow, navigation conditions were slightly more difficult for inbound and outbound movements due to stronger crosscurrents inland of the GEB at the confluence of the Pines and Saugus Rivers.

Plan 1

In general, navigation conditions with Plan 1 were more difficult than those observed with base conditions and were not satisfactory, particularly when the vessel was moving in the direction of the flow. The crosscurrents between the GEB and the flood-control structure caused difficulties in maintaining alignment with the navigation spans of the GEB and the flood-control structure. Also,

there were changes in flow patterns in the vicinity of the navigation gate of the flood-control structure that caused difficulties for navigation.

Plan 2

These tests produced the following results:

- a. Plan 2 was developed in an effort to reduce the crosscurrents observed in the navigation channel between the GEB and the flood-control structure with Plan 1 conditions.
- b. These tests indicated that navigation conditions between the GEB and the flood-control structure were satisfactory. However, navigation conditions approaching the two structures were about the same as or more difficult than those observed with Plan 1. This is particularly true for vessels moving in the direction of flow.
- c. With the spring tide and flood flow, navigation conditions for inbound tankers were difficult due to the north-to-south crosscurrent in the navigation channel approaching the navigation gate. Inbound tankers had a tendency to be moved toward or into the south pier of the navigation gate.
- d. Navigation conditions for outbound tankers approaching the GEB for the spring tide and ebb flow were not significantly different from those observed with Plan 1.

Plans 2A and 2B

These tests indicated that extensive dredging seaward of the flood-control structure to reduce or eliminate the north-to-south crosscurrents observed with Plan 1 were not successful.

Plan 2C +3 and Plan 2C +7

These tests produced the following results:

- a. These tests indicated that navigation conditions for the tanker would be about the same as those observed with Plan 2. Tankers moving in the direction of flow could become misaligned when approaching either the navigation gate or the navigation span of the GEB. As observed with other tests, the tanker would most likely wait until a slack period in the tide to either deliver the jet fuel to the G.E. plant or leave the G.E. plant in ballast.

- b. Navigation conditions were satisfactory for small vessels (in this case the lobster boat) both inbound and outbound with all conditions tested. With spring tide and flood flow, the crosscurrent in the navigation channel approaching the flood-control structure tended to move the lobster boat from the north toward the south. However, this tendency was not considered to cause an unsafe condition.
- c. With the spring tide and ebb flow, outbound traffic had some difficulty trying to maintain alignment into the navigation span of the GEB, which impacted on the approach to the navigation gate of the flood-control structure. However, this was not considered to cause an unsafe condition.
- d. The model study indicated that the flood-control structure should be configured similar to that shown in Plan 2C. This scheme appeared to convey the flow sufficiently and provided satisfactory navigation conditions for small vessels entering and leaving the estuary. Since larger vessels (tankers) would most likely wait until a slack period in the tidal cycle to enter or leave the estuary, the construction of the flood-control structure as shown in Plan 2C should not have an adverse impact on passage through the estuary.

Construction sequence, Alternative 2

Navigation conditions for Alternative 2 were satisfactory for all stages of construction and all flow tested. Although navigation conditions were considered satisfactory, in general, each stage of construction did cause some difficulties for traffic entering or leaving the estuary. The navigation difficulties generally occurred with the spring tide.

Construction sequence, Alternative 1

Since Alternative 1 is basically the same construction scheme as Alternative 2 with a few exceptions, it is believed that by reducing current magnitudes for Stages 1 and 2, navigation conditions would be improved compared to those observed with Alternative 2.

Construction sequence, Alternative 3

These tests produced the following results:

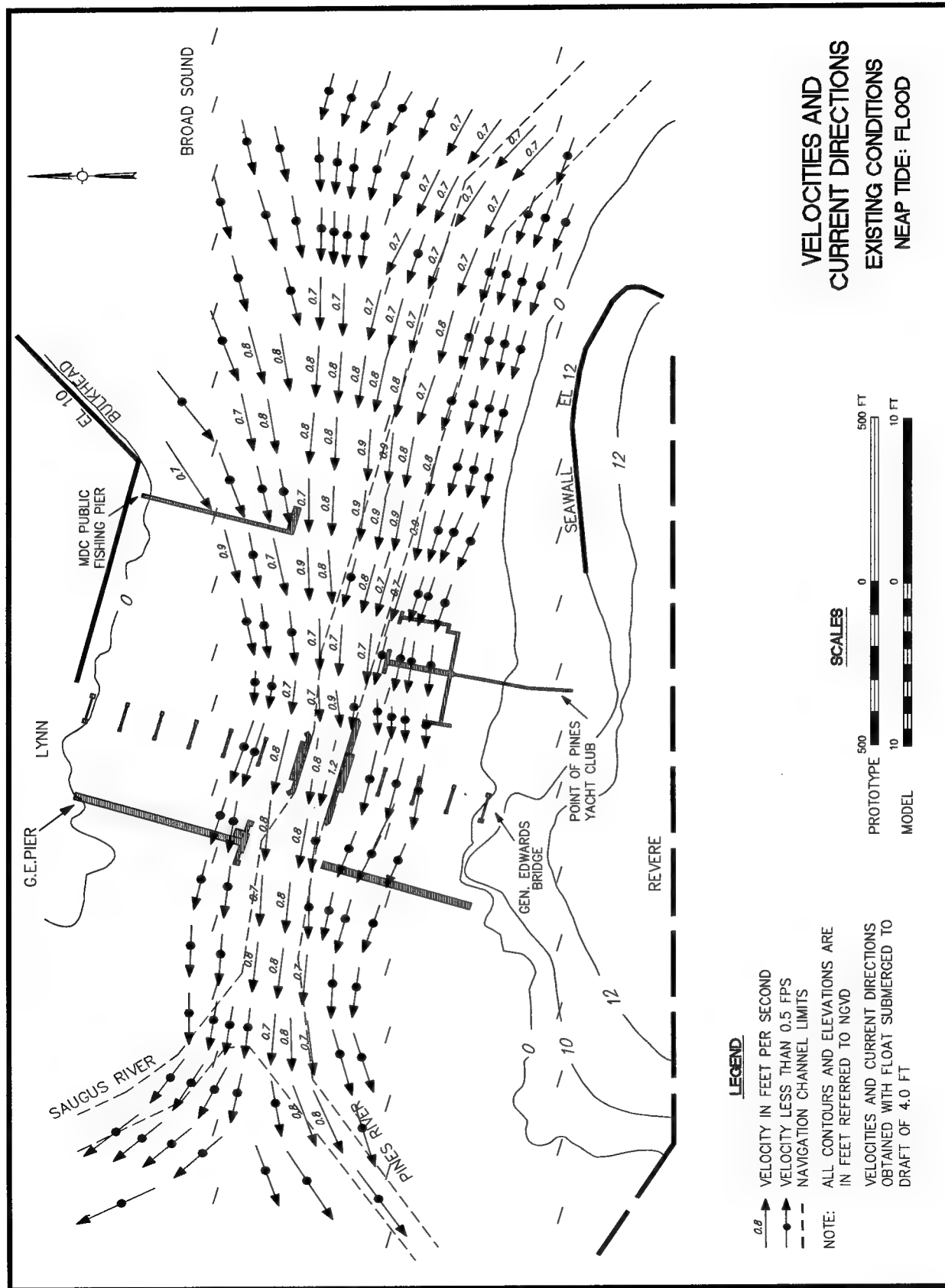
- a. Although Alternative 3 was not fully documented, navigation conditions were unsatisfactory for Stage 2 with the spring tide and flood flow. With Stage 2 and flood flow, inbound traffic was likely to strike the south bridge fender of the GEB or not be able to align with the navigation span of the GEB.

- b. The model study indicated that Alternative 1 would be least likely to adversely affect navigation entering and leaving the estuary during the construction period. Alternative 2 would be the second choice as a possible construction scheme. Alternative 3 would have the most adverse effects on navigation entering and leaving the estuary.

Bulkhead tests, Alternative 2

These tests produced the following results:

- a. The model study indicated that the tainter gate installation for flushing gate 6 will need to be accomplished during Stage 2 of construction.
- b. The tainter gates for flushing gates 7 and 8 could be installed during Stage 3 construction, provided they were not installed concurrently with each other.
- c. The tainter gates for flushing gates 1 and 2 could be installed during Stage 4 construction; however, caution should be exercised during this time due to an increase in crosscurrent approaching the navigation gate with both flood and ebb flow. Navigation conditions were more difficult than those observed with normal Stage 4 construction. It should be noted that evaluation of navigation conditions was based on marginally powered vessels, and vessels with more power and steering capabilities could overcome some of these difficulties.
- d. The tainter gates for flushing gates 4 and 5 could be installed at the same time, provided the Stage 4 splitter wall remained in place until installation of the tainter gates was complete. Navigation conditions were very similar to those observed with normal Stage 4 construction.
- e. Installation of the tainter gate for flushing gate 3 would be accomplished last. Navigation conditions were satisfactory for inbound and outbound traffic with ebb and flood flow.
- f. A system of current vanes or some device to indicate current direction and magnitude to boaters may improve the way the mariner might interpret and react to the flow conditions. This would be particularly helpful during the construction period of the project.



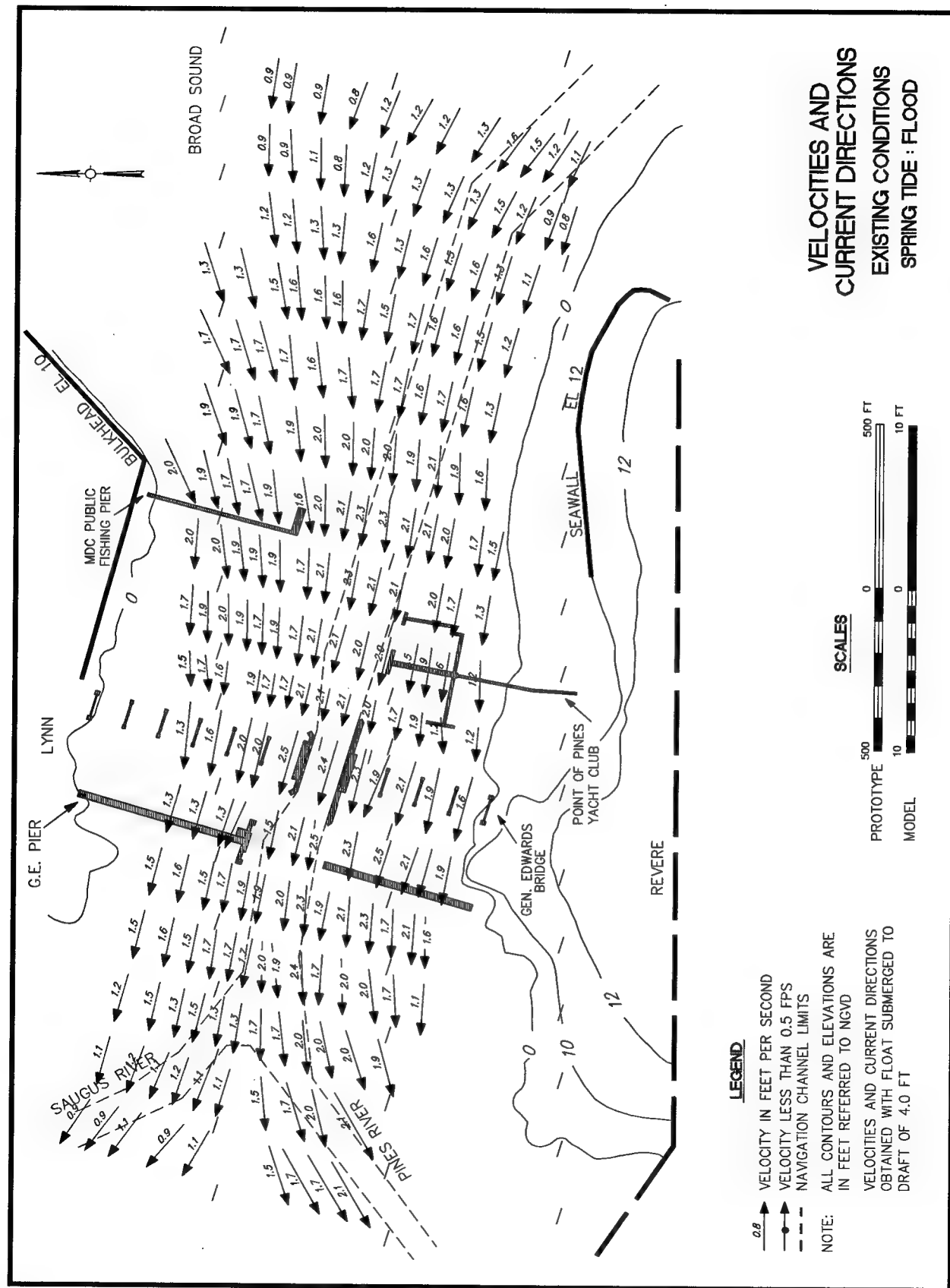


Plate 2

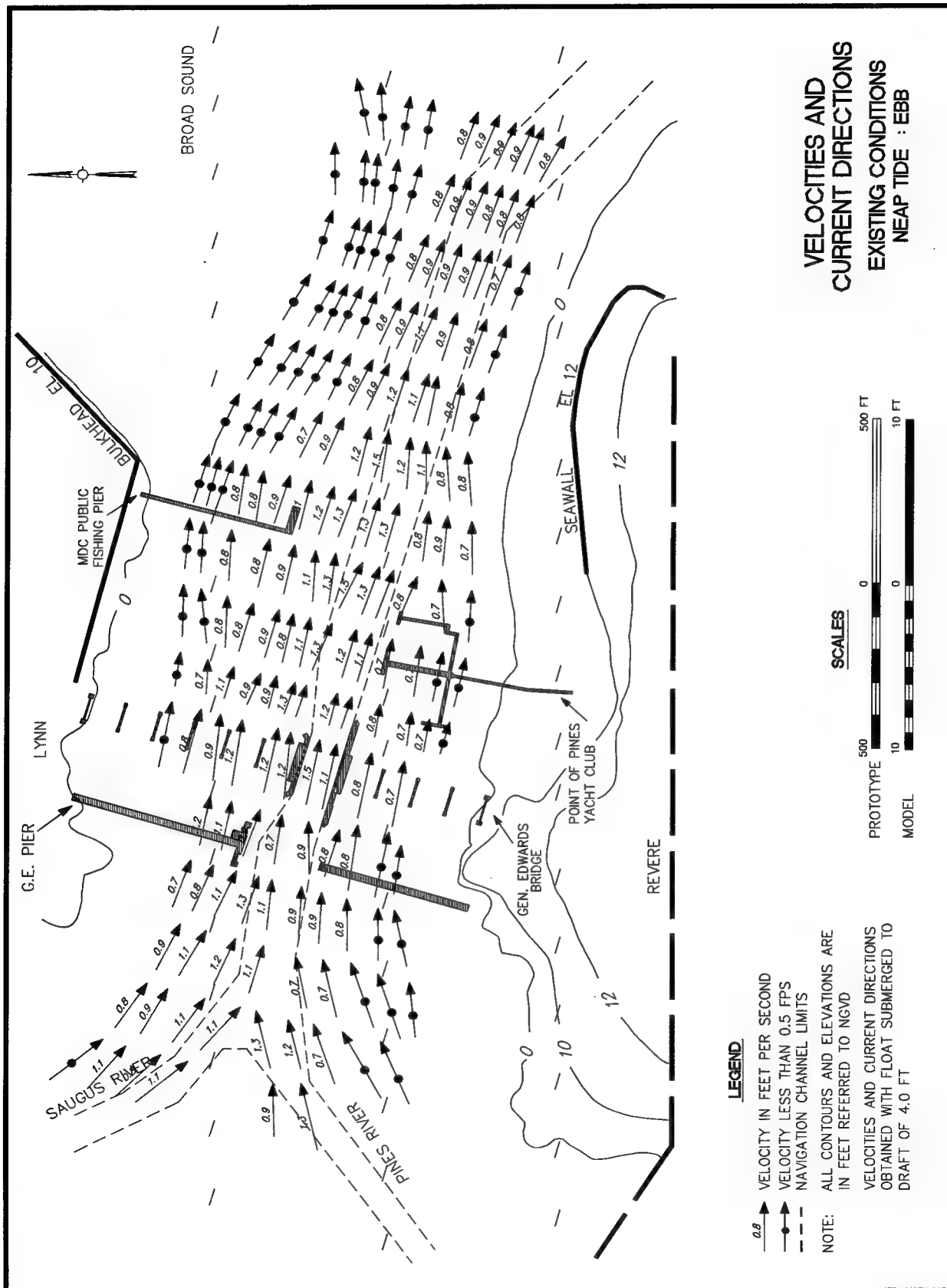
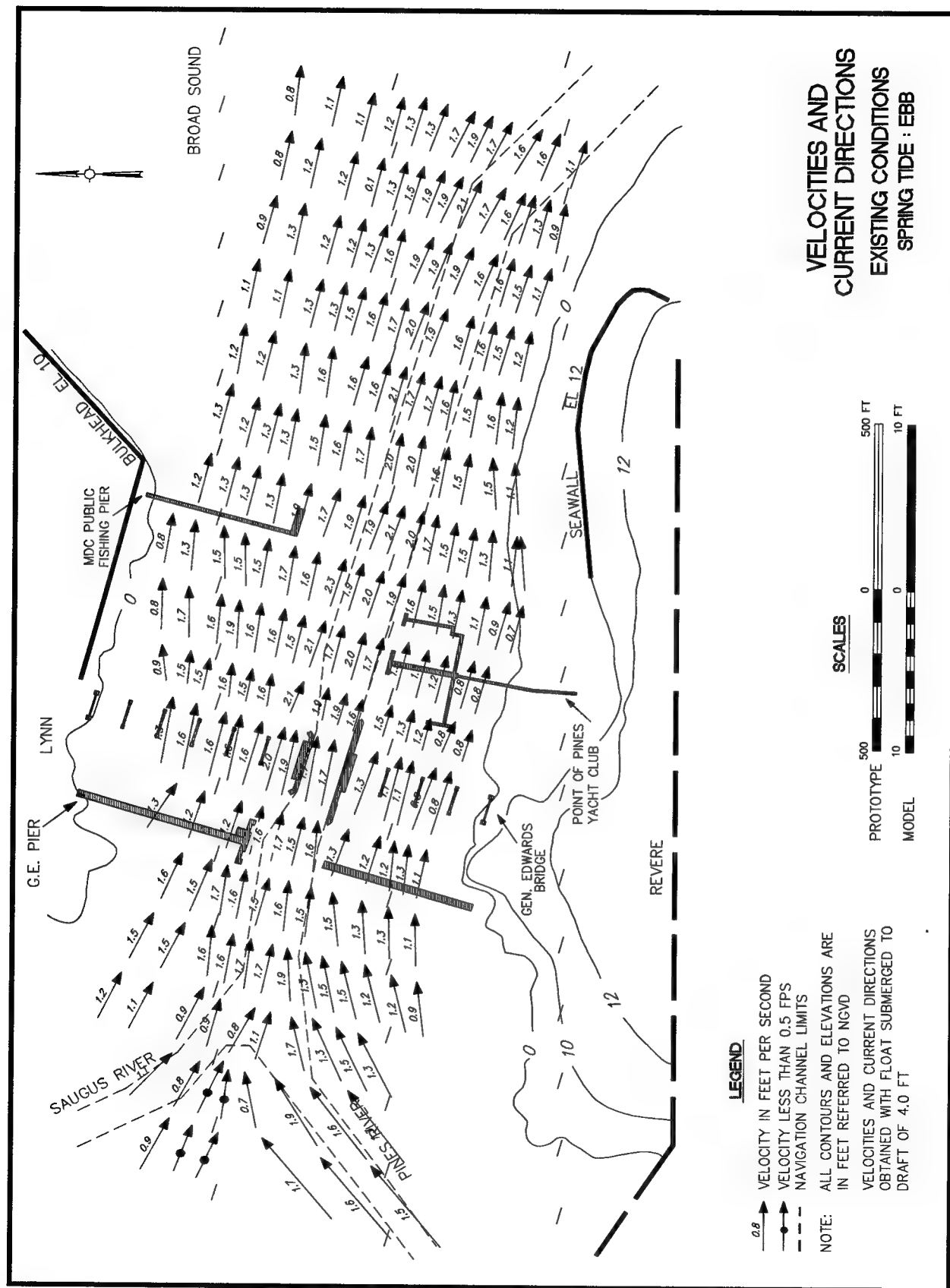
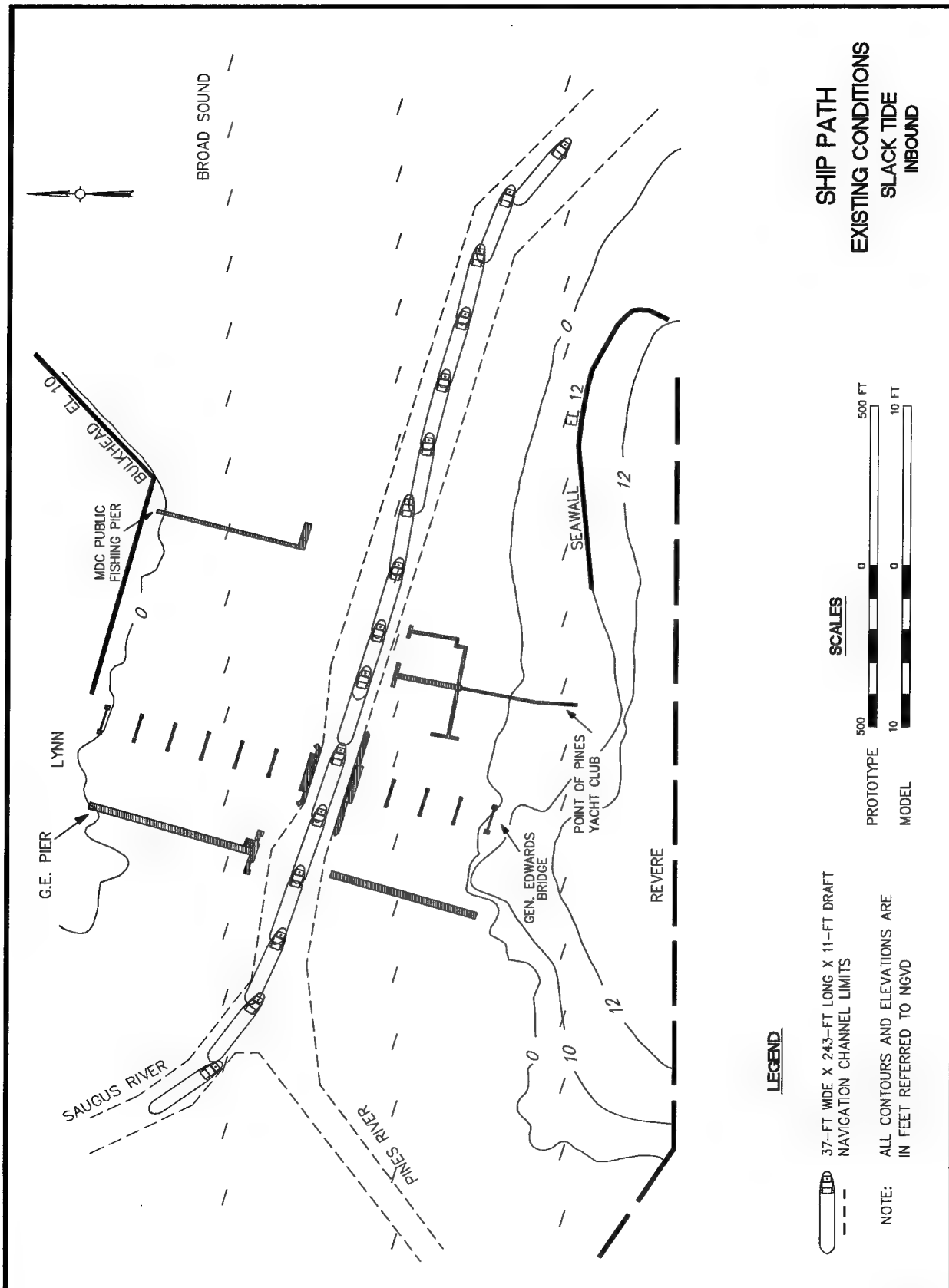


Plate 3





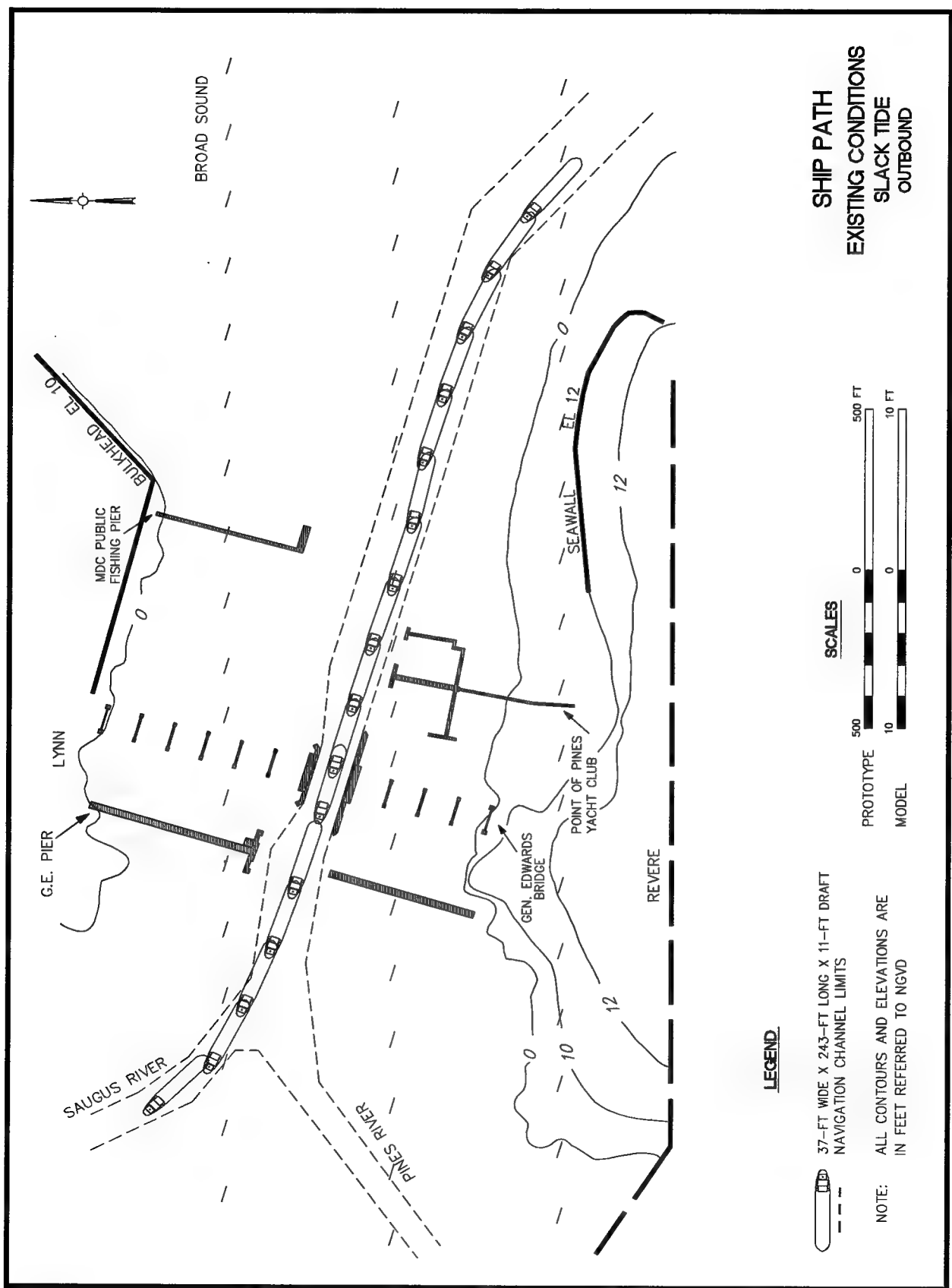
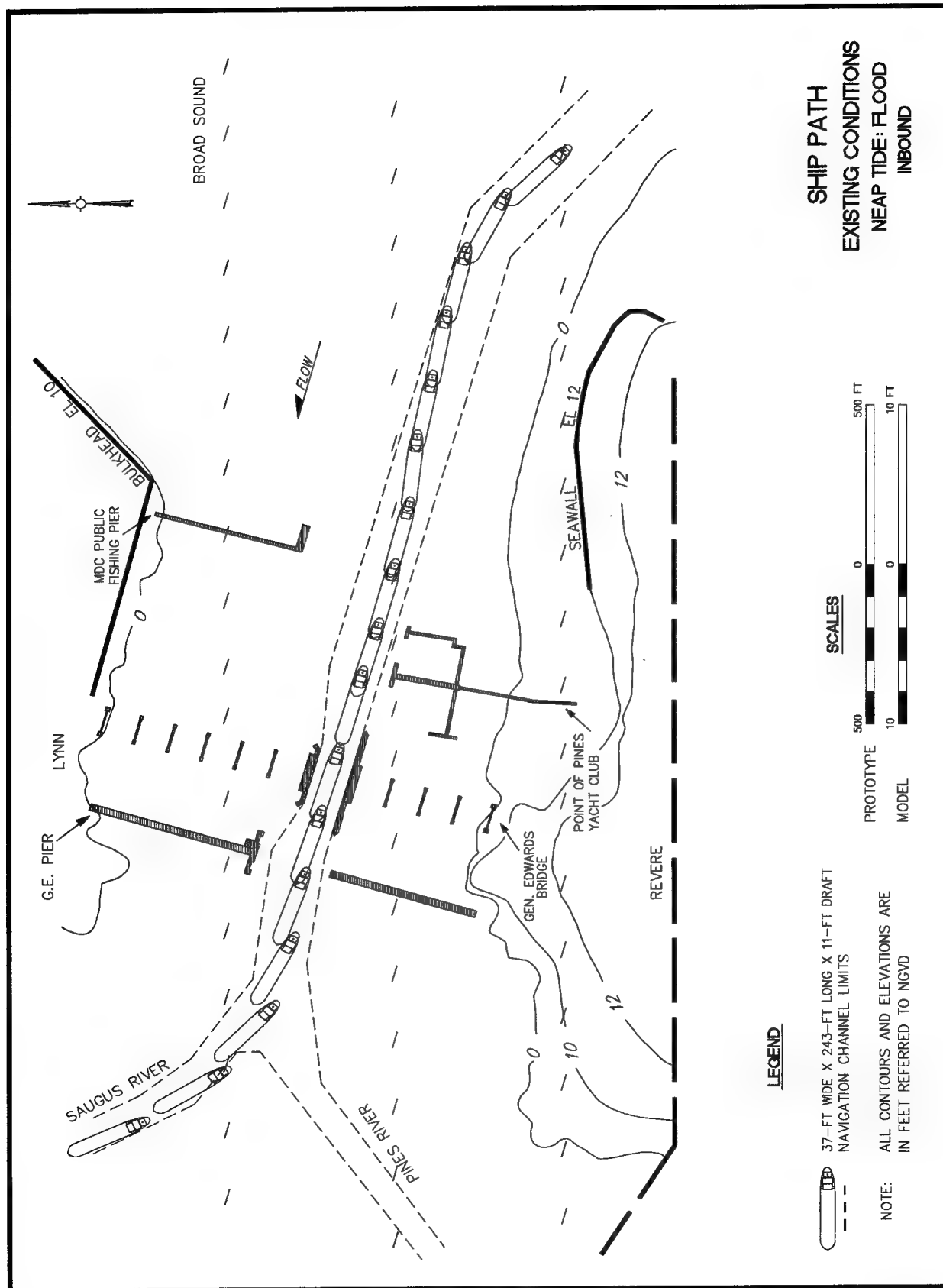


Plate 6



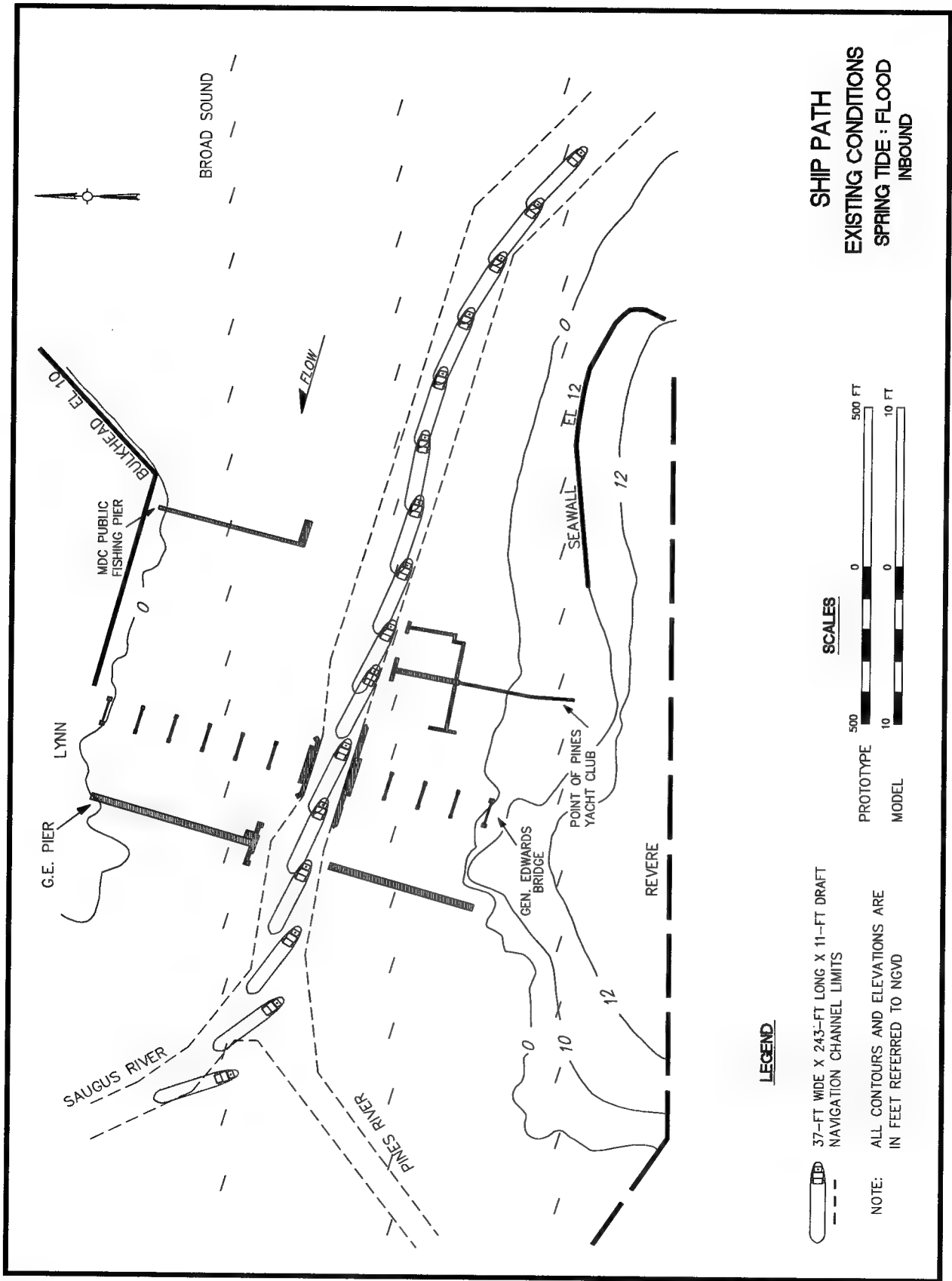
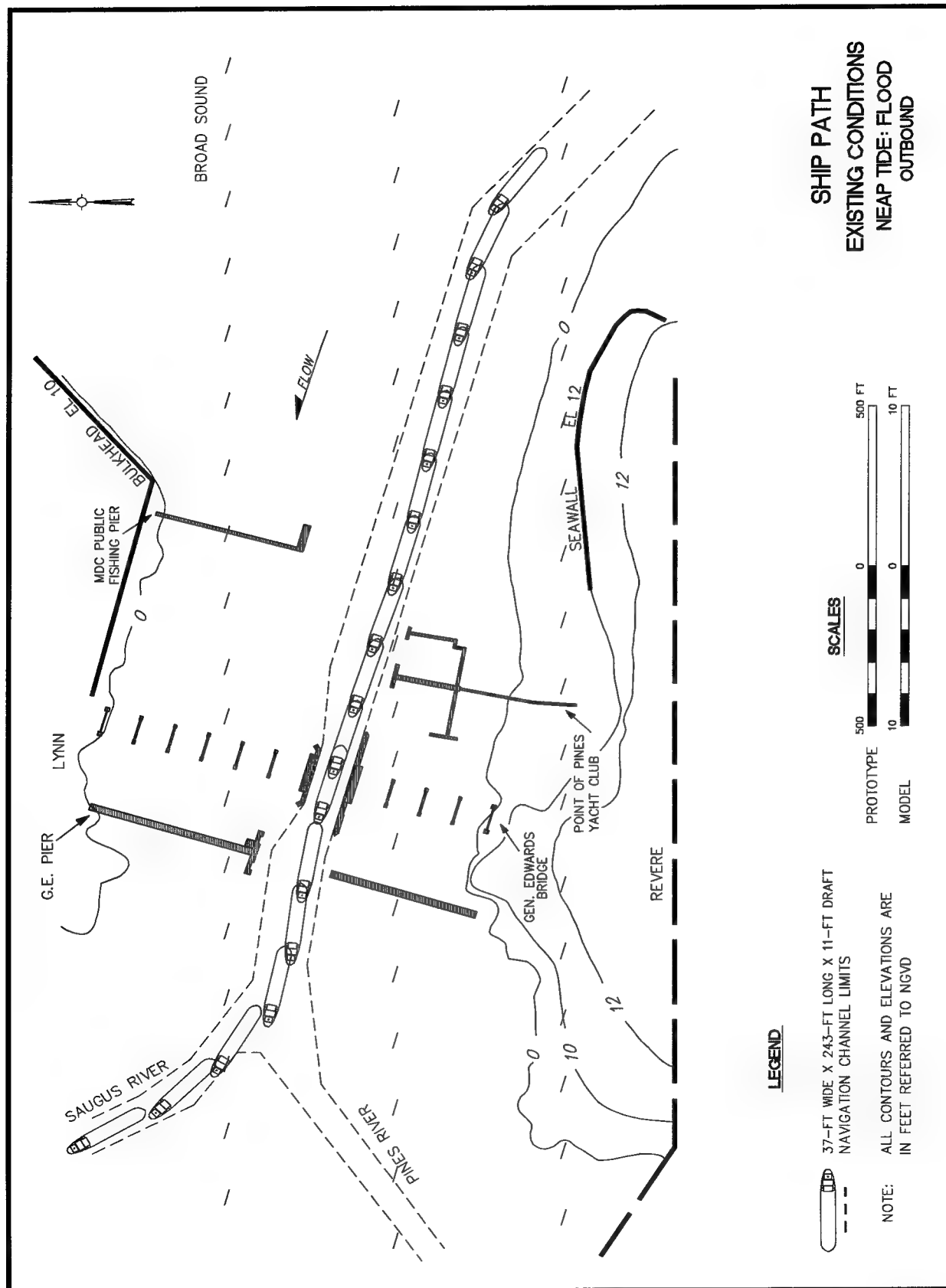


Plate 8



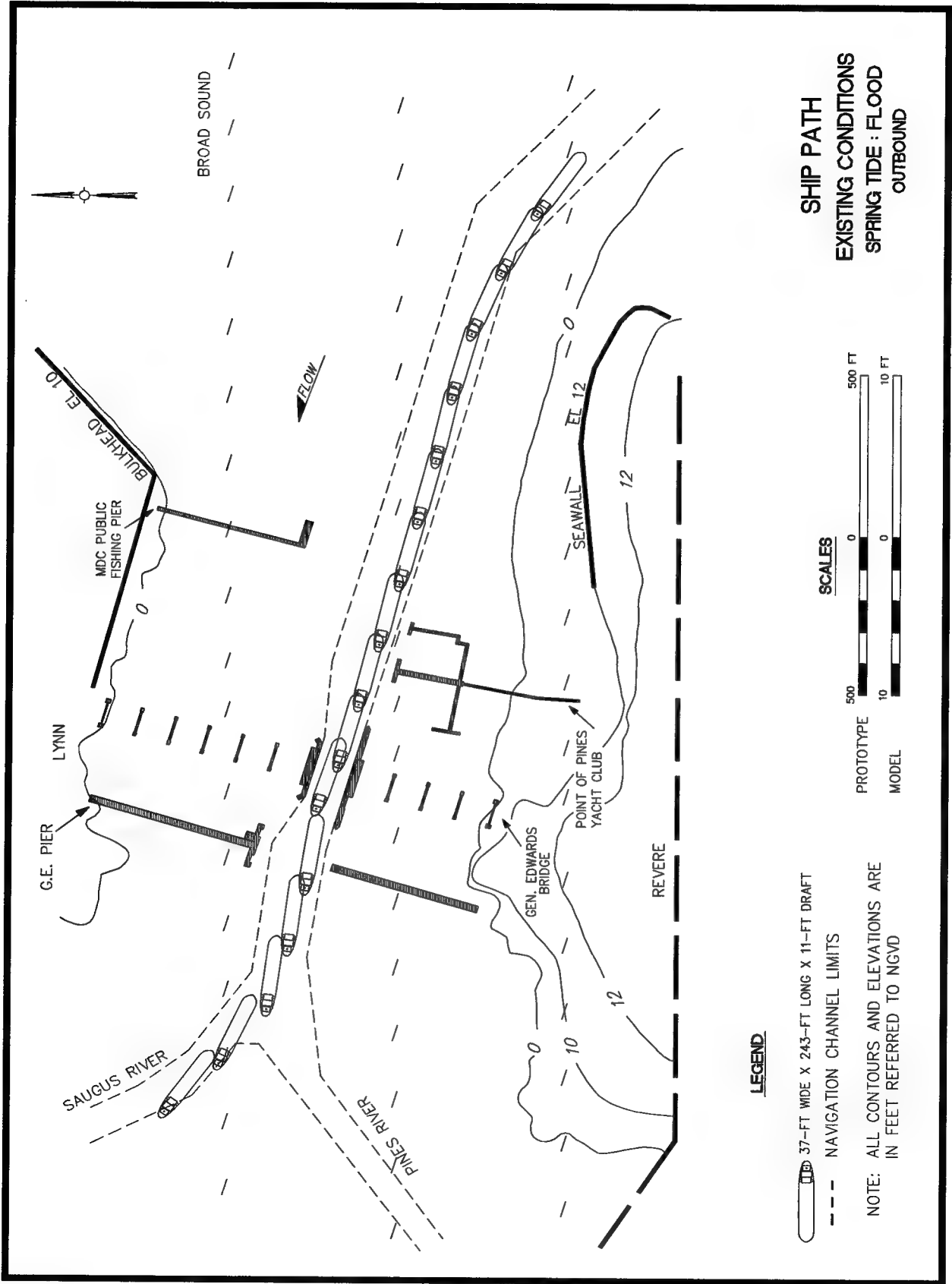
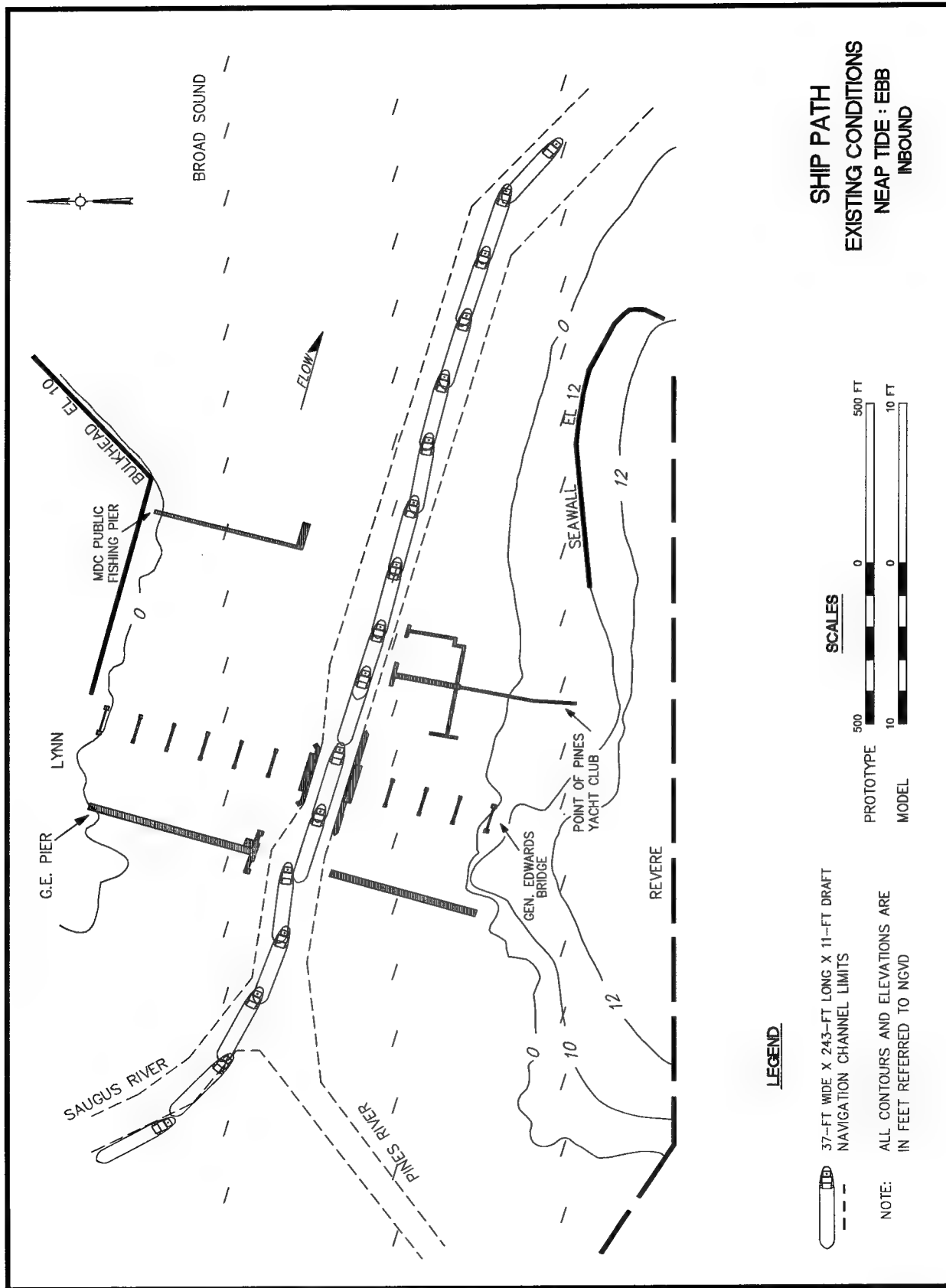


Plate 10



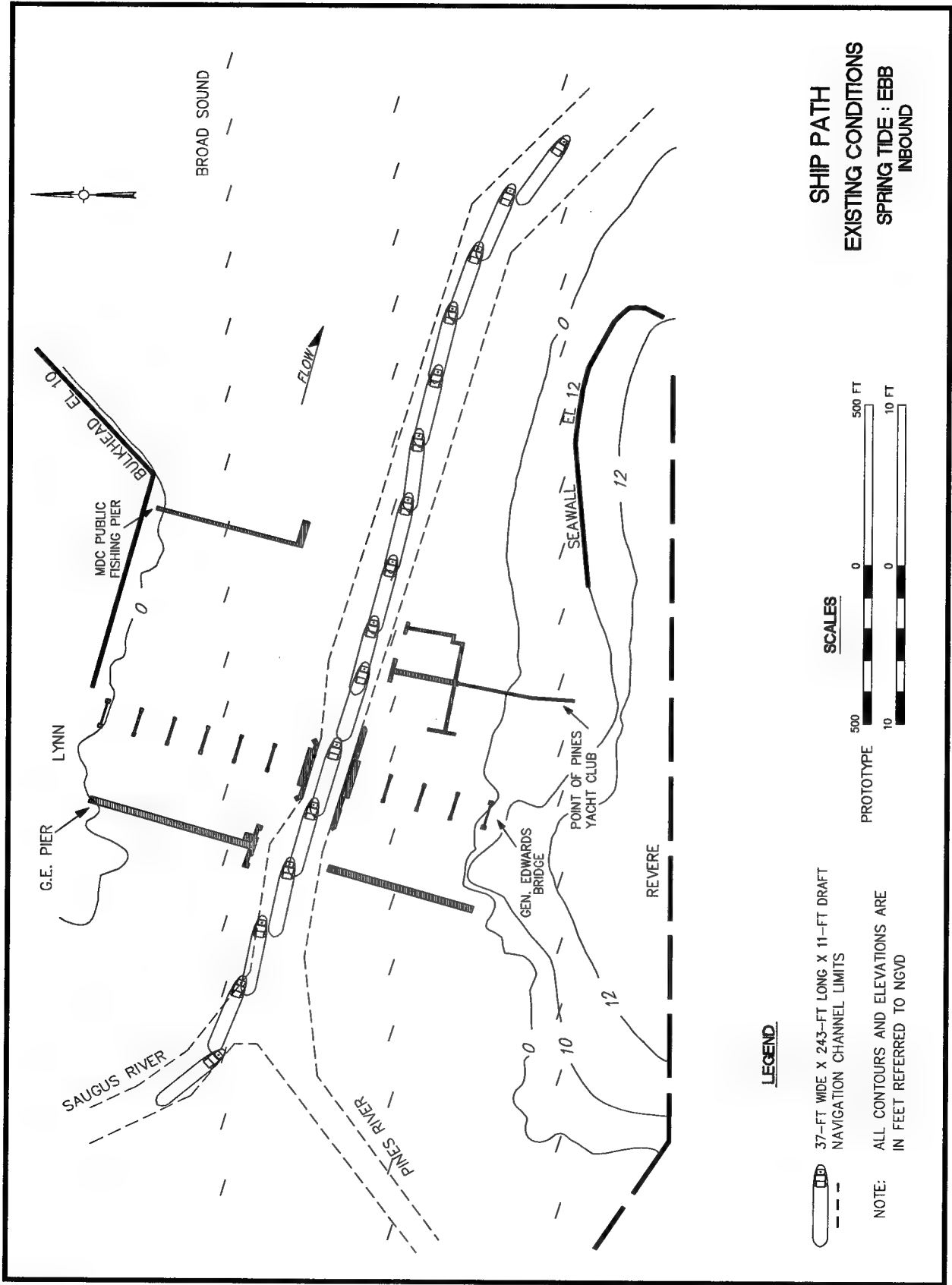
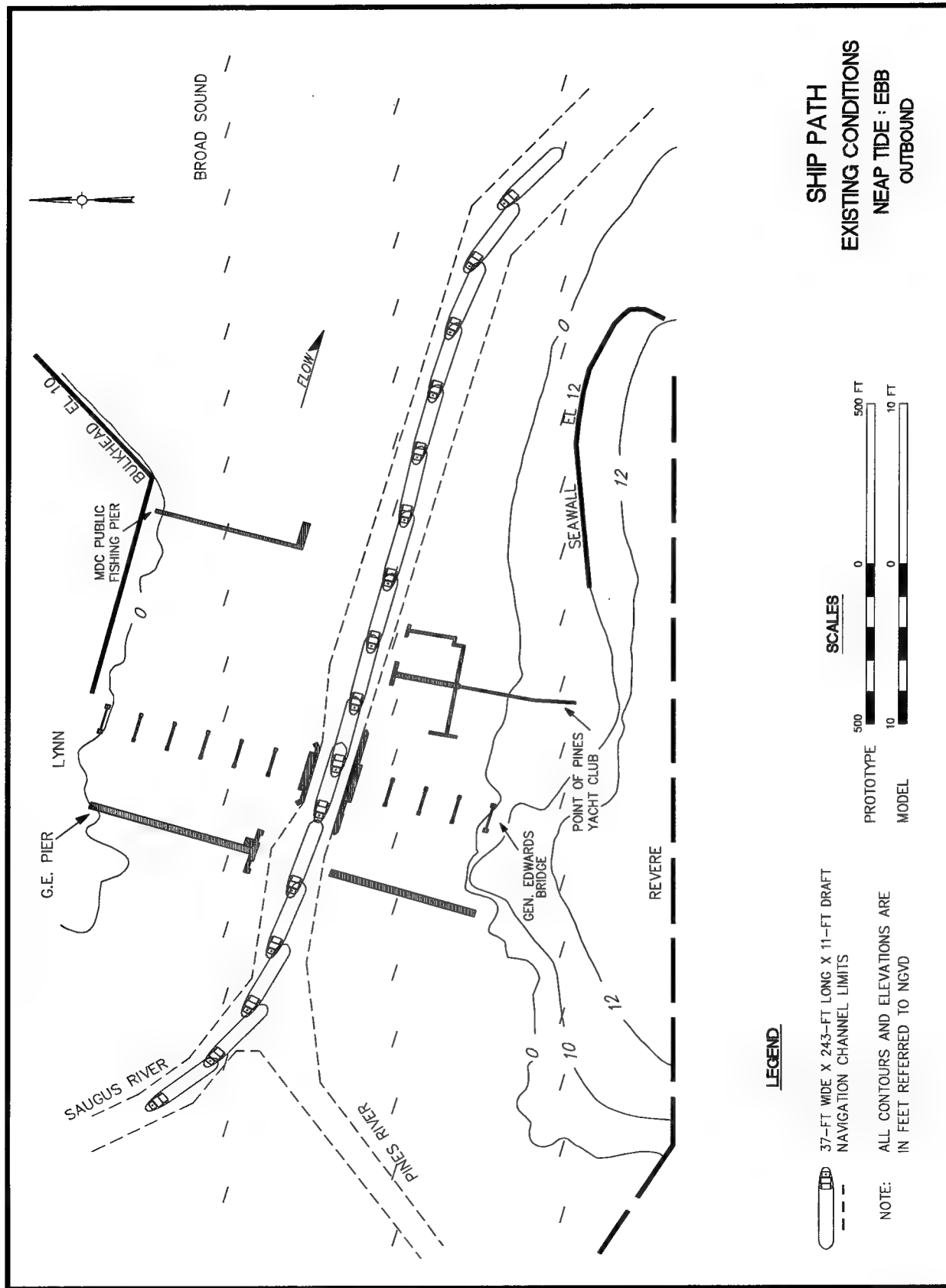


Plate 12



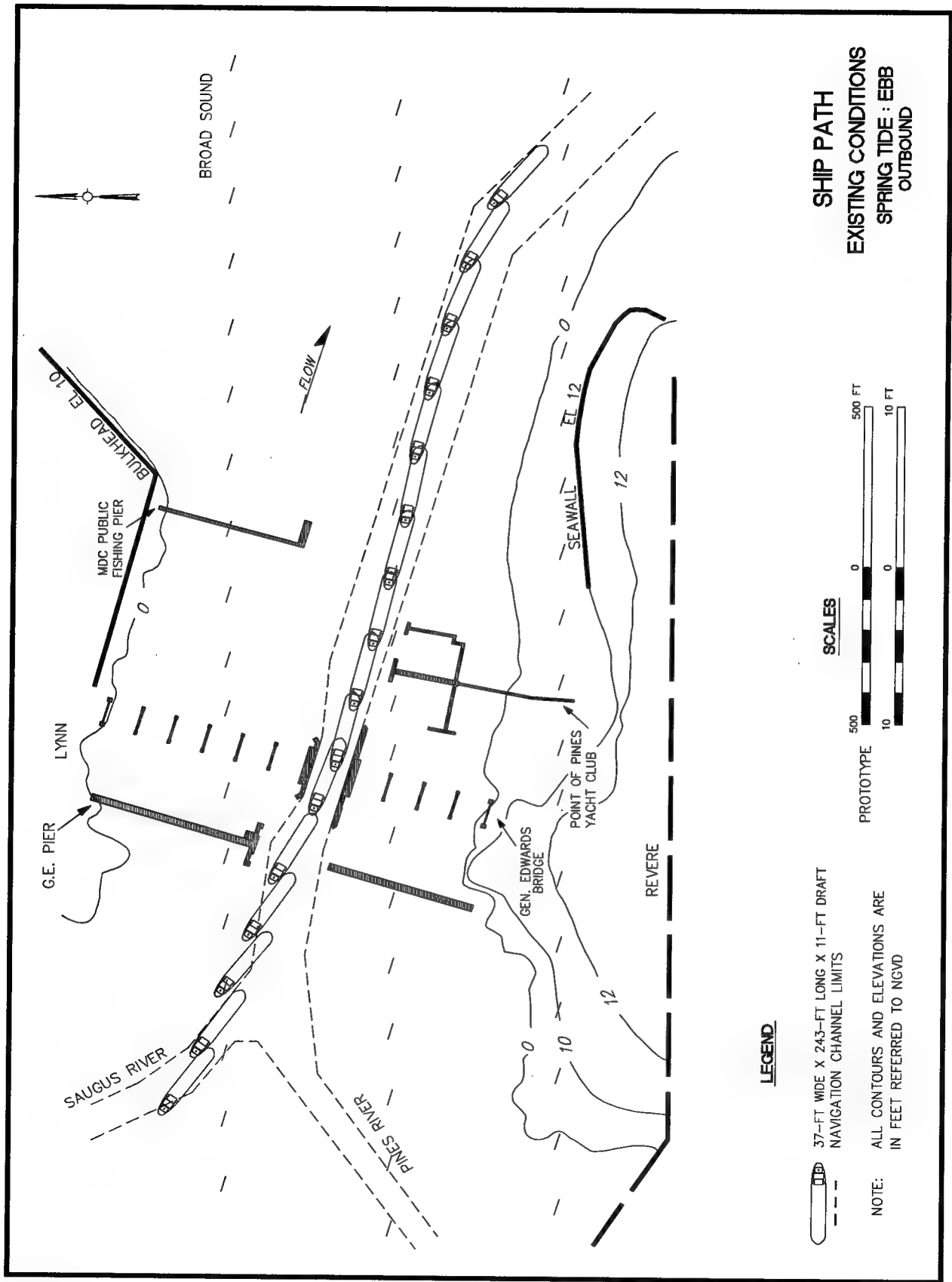
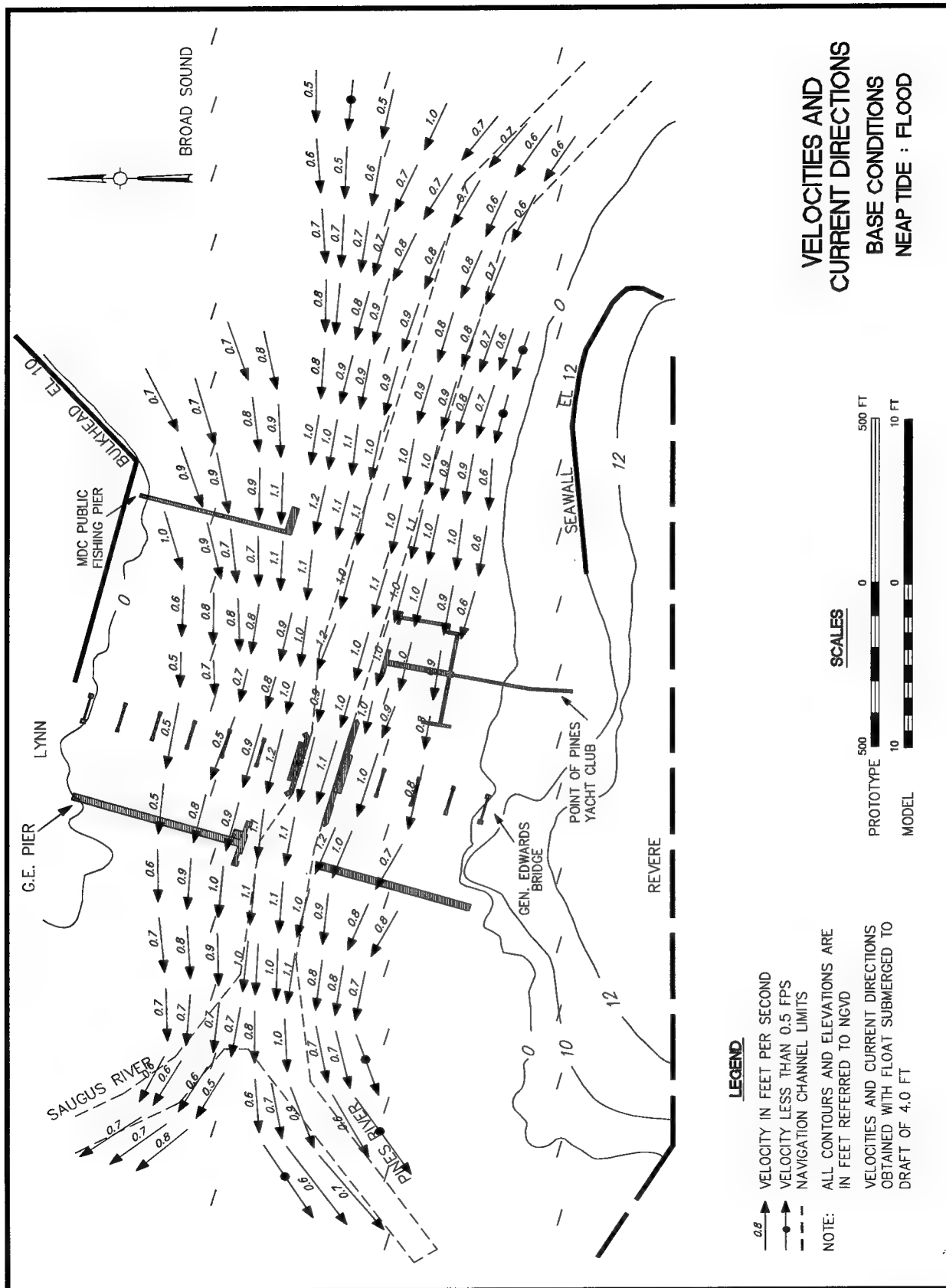


Plate 14



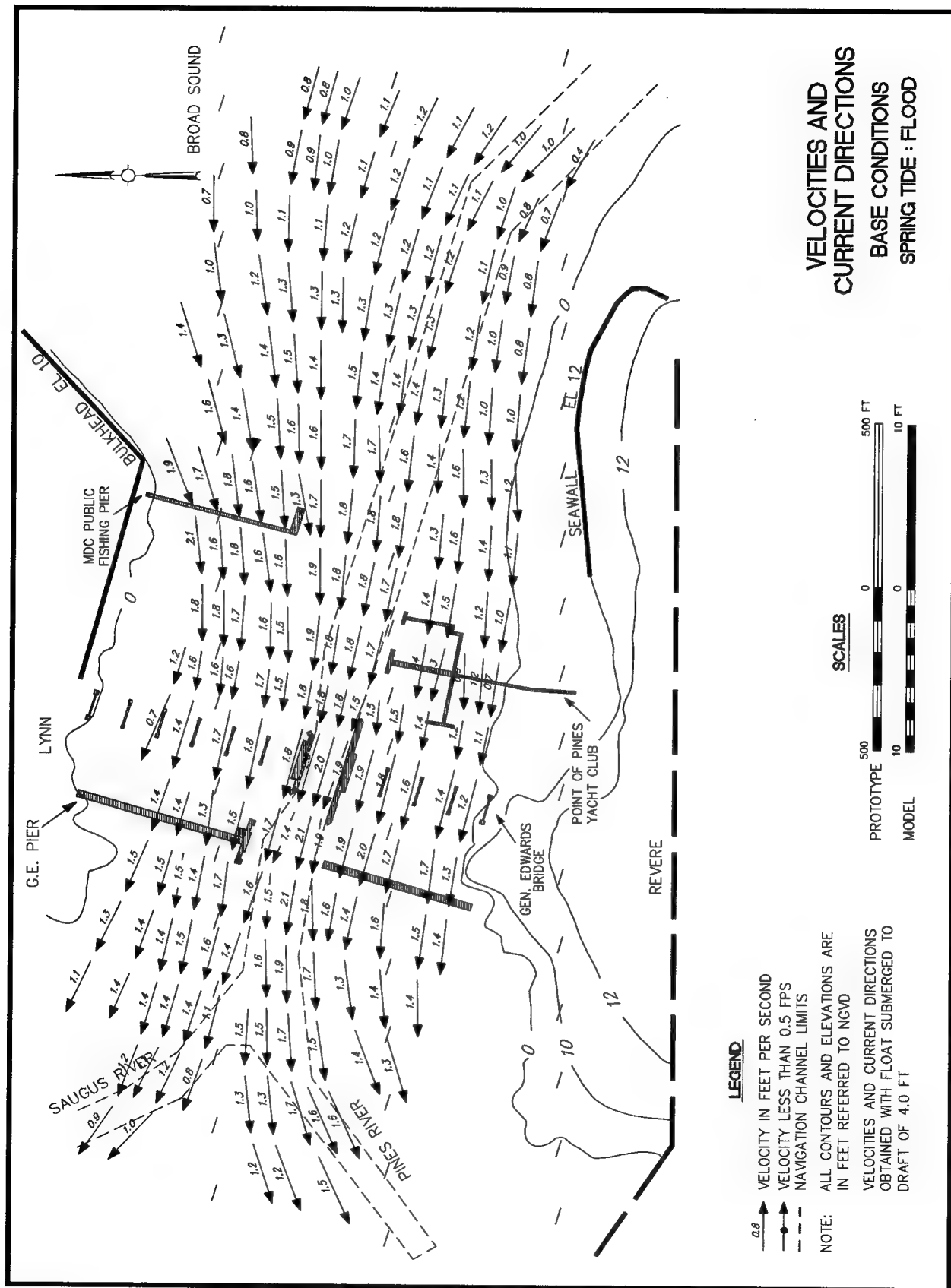
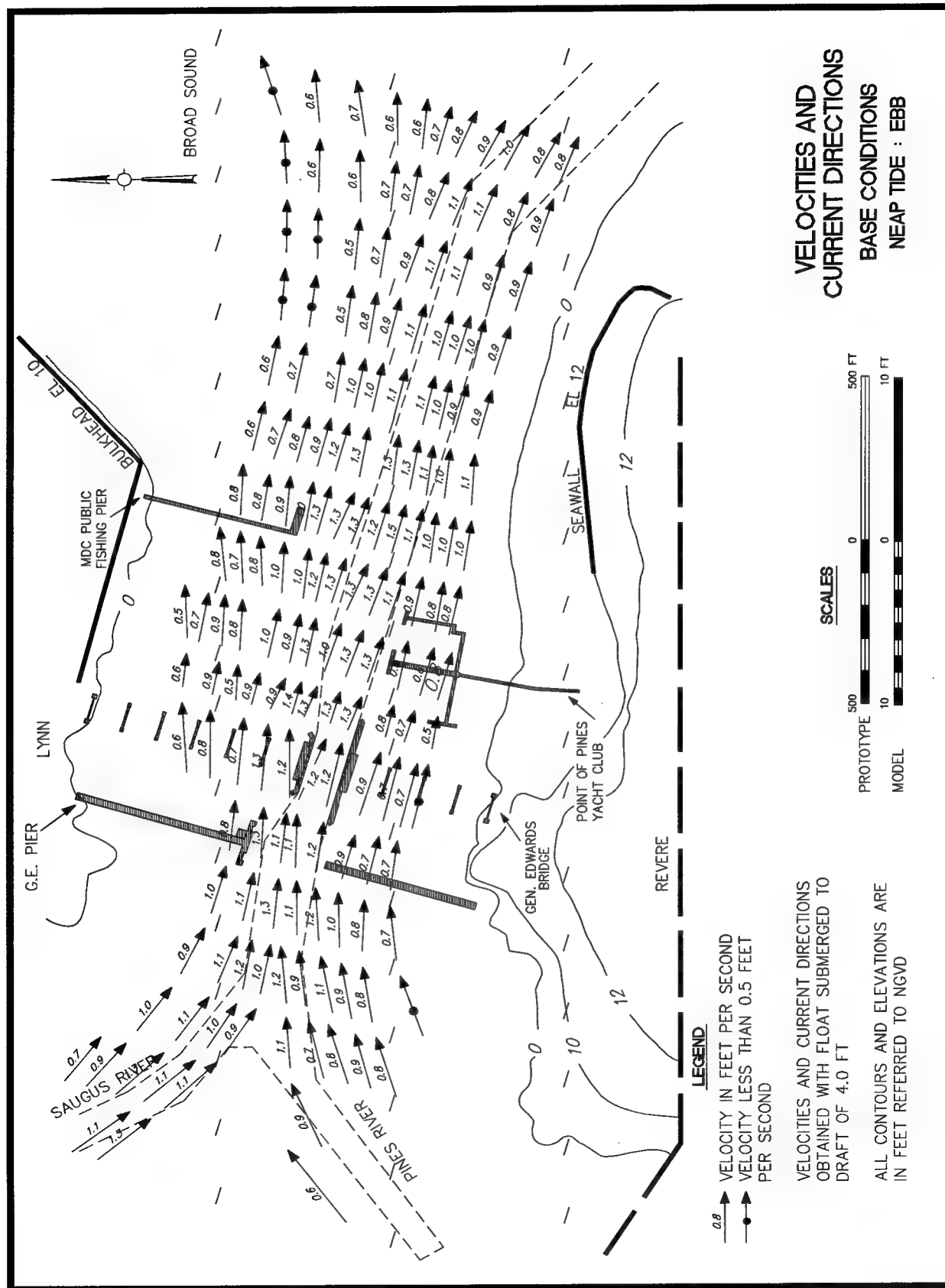
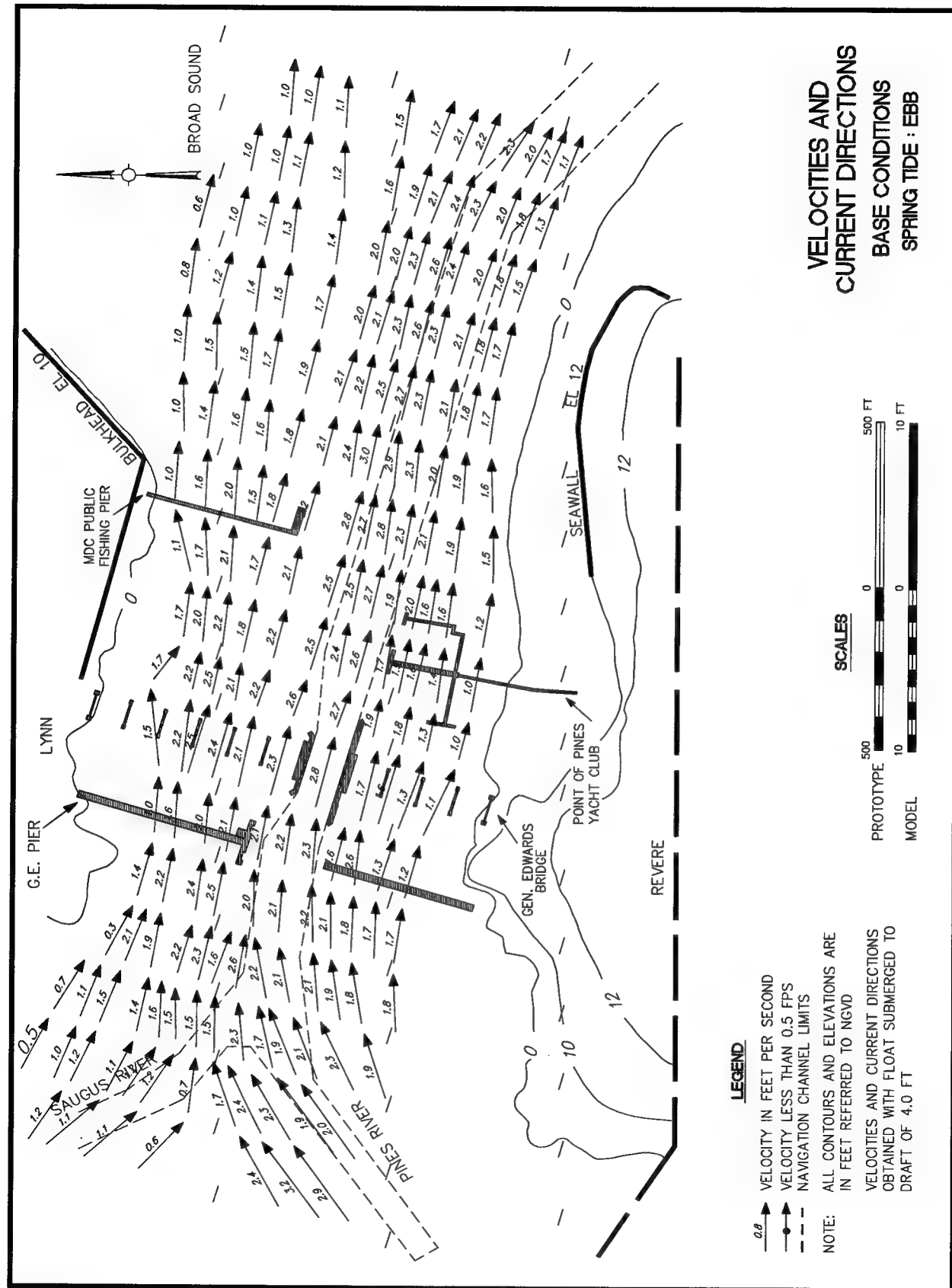
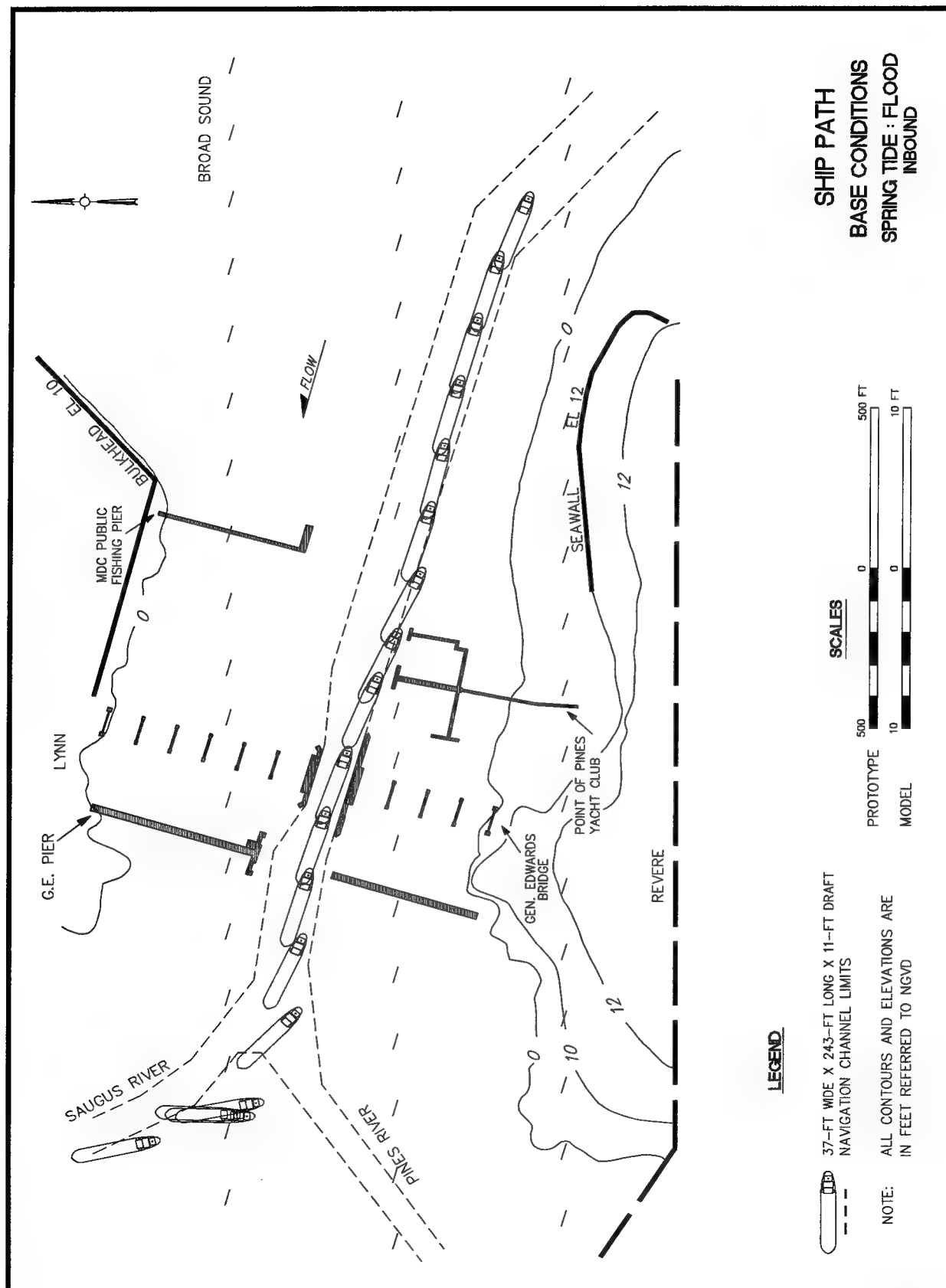
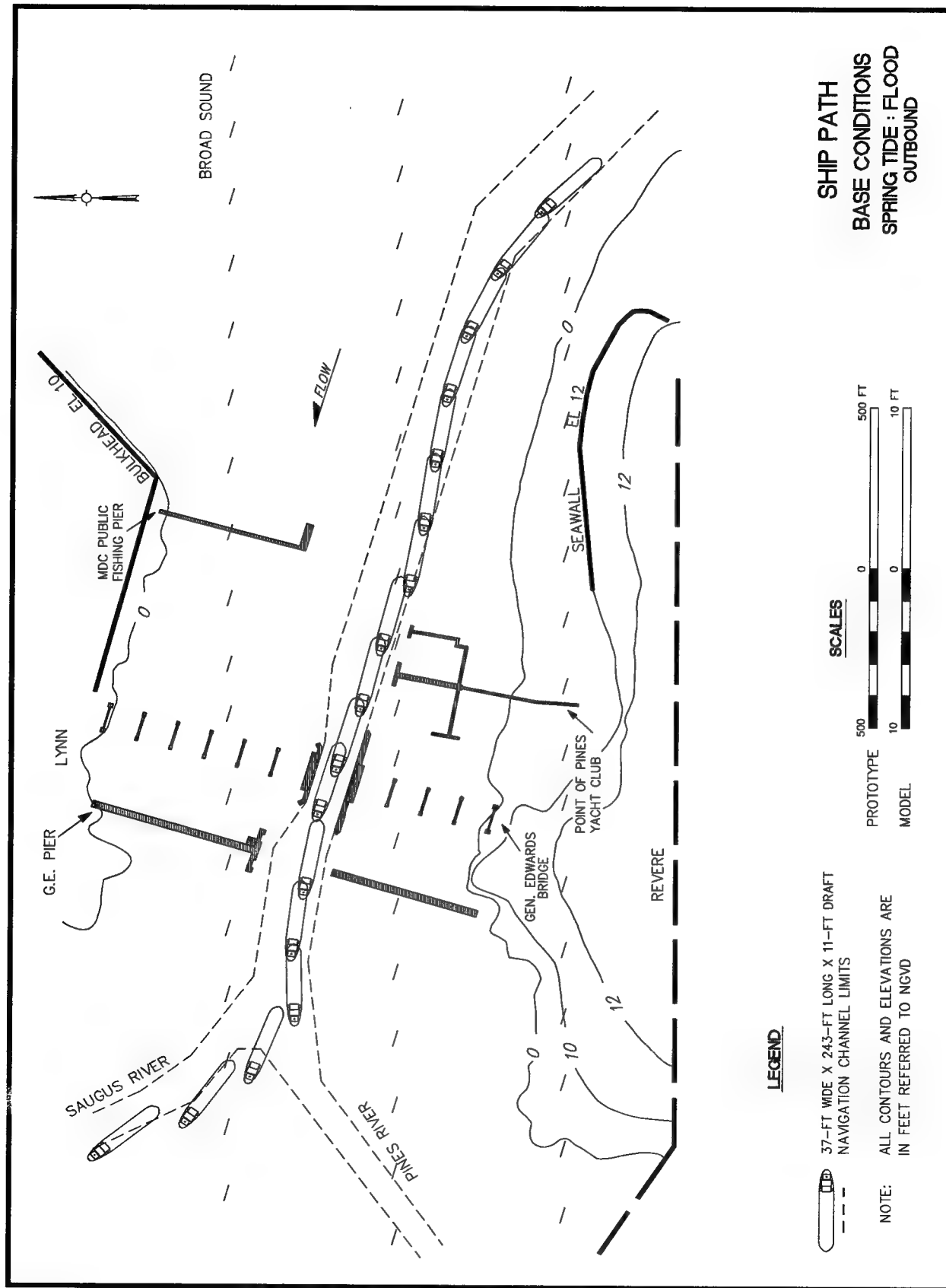


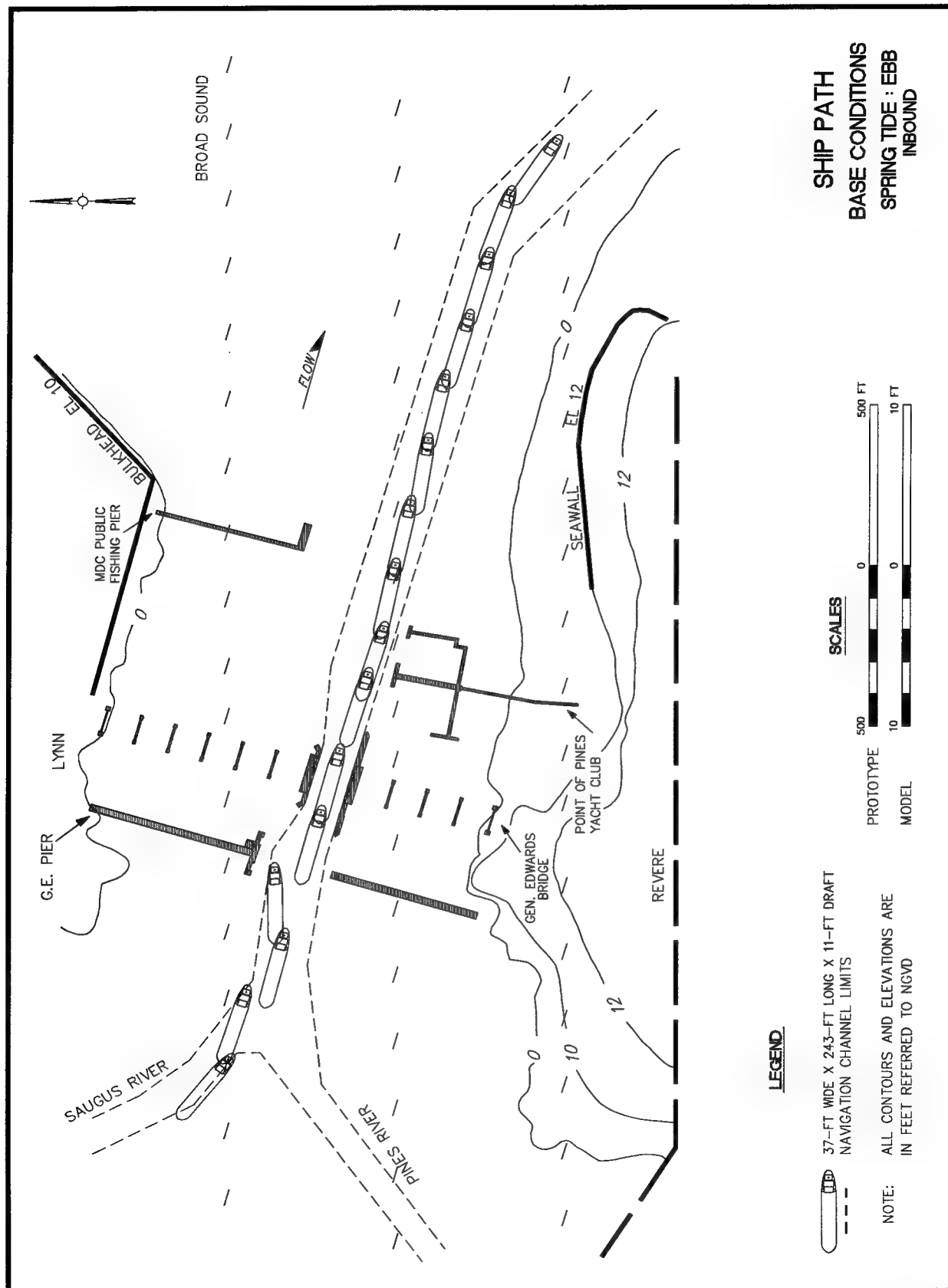
Plate 16











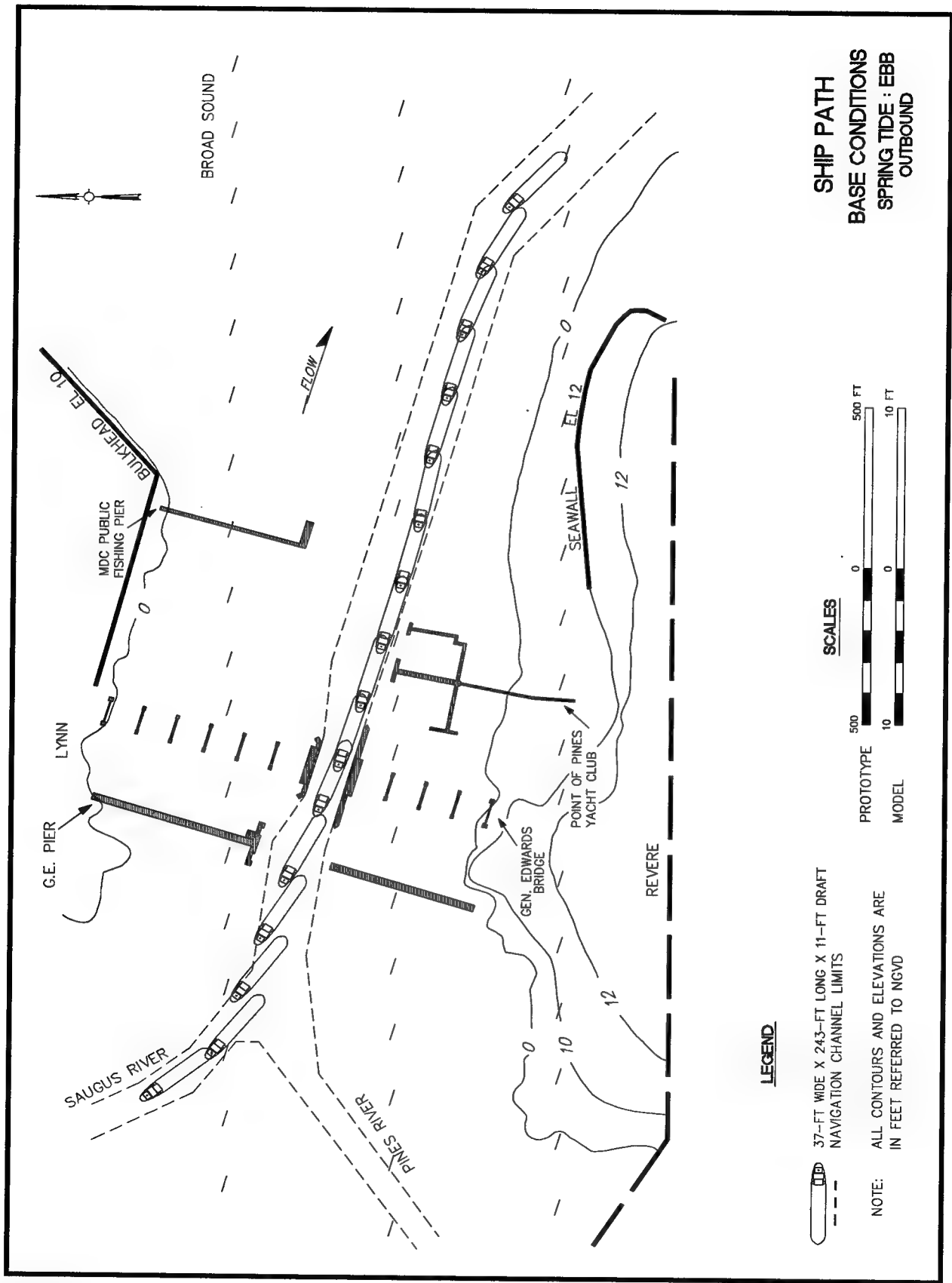
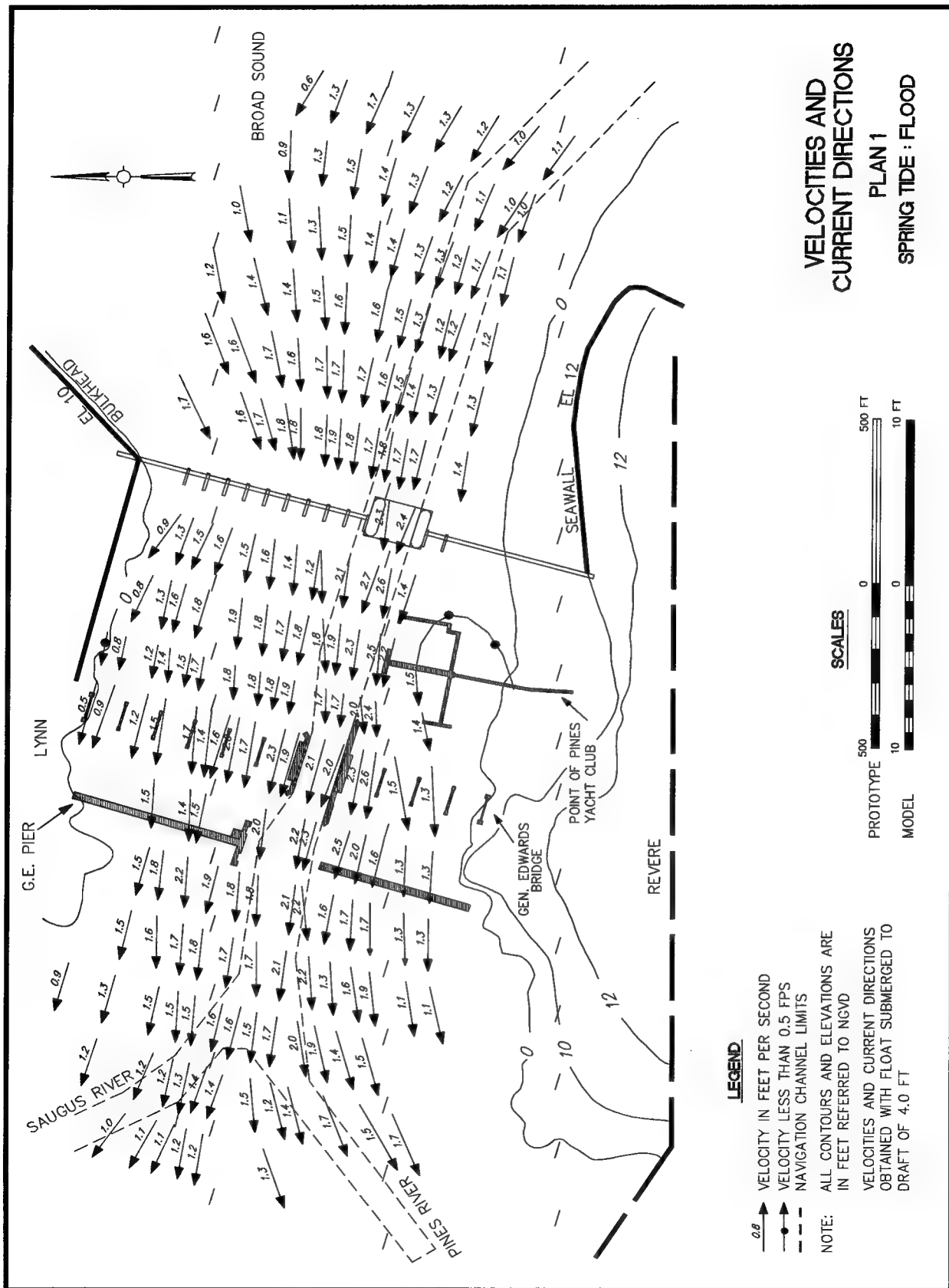
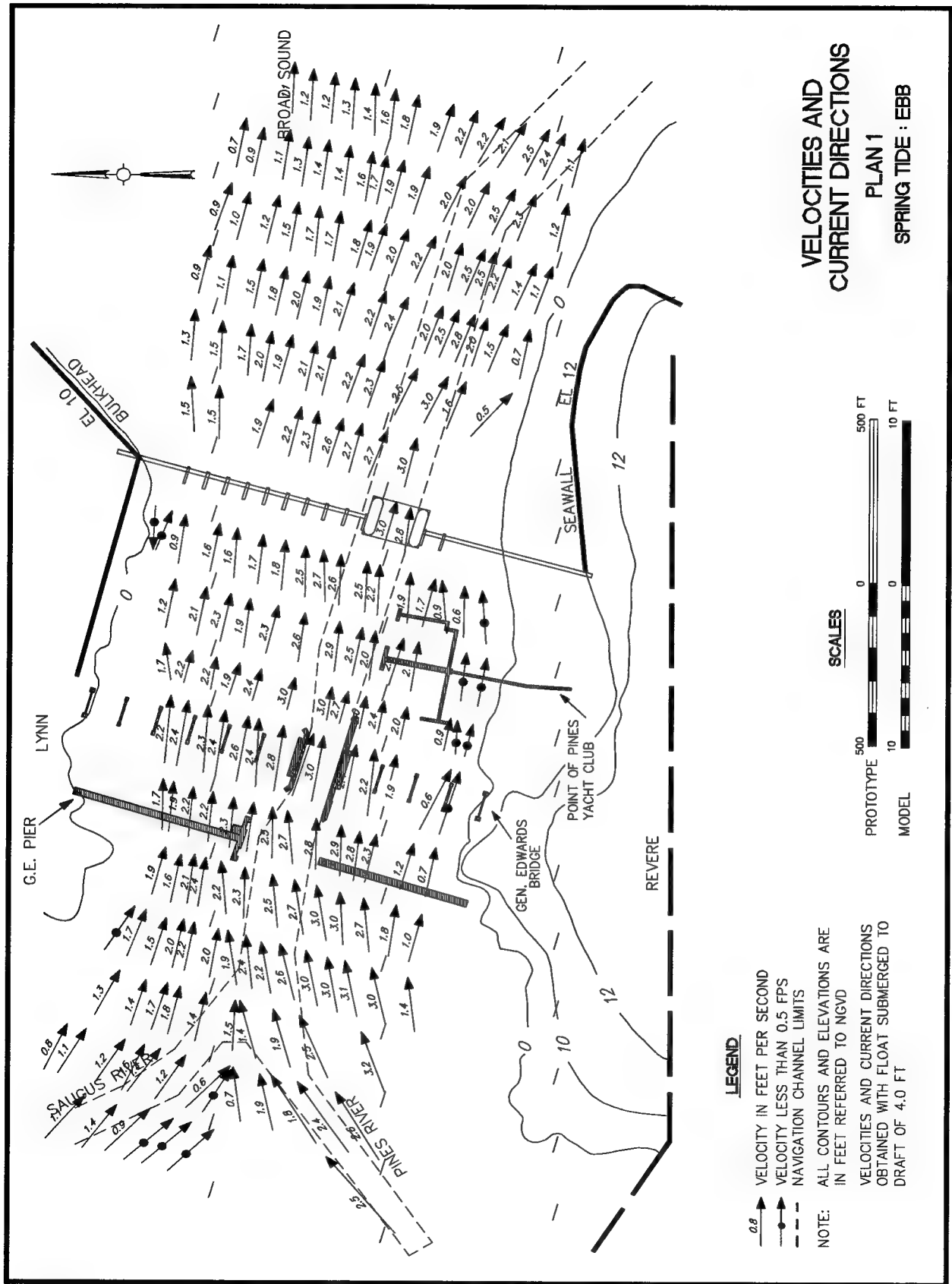
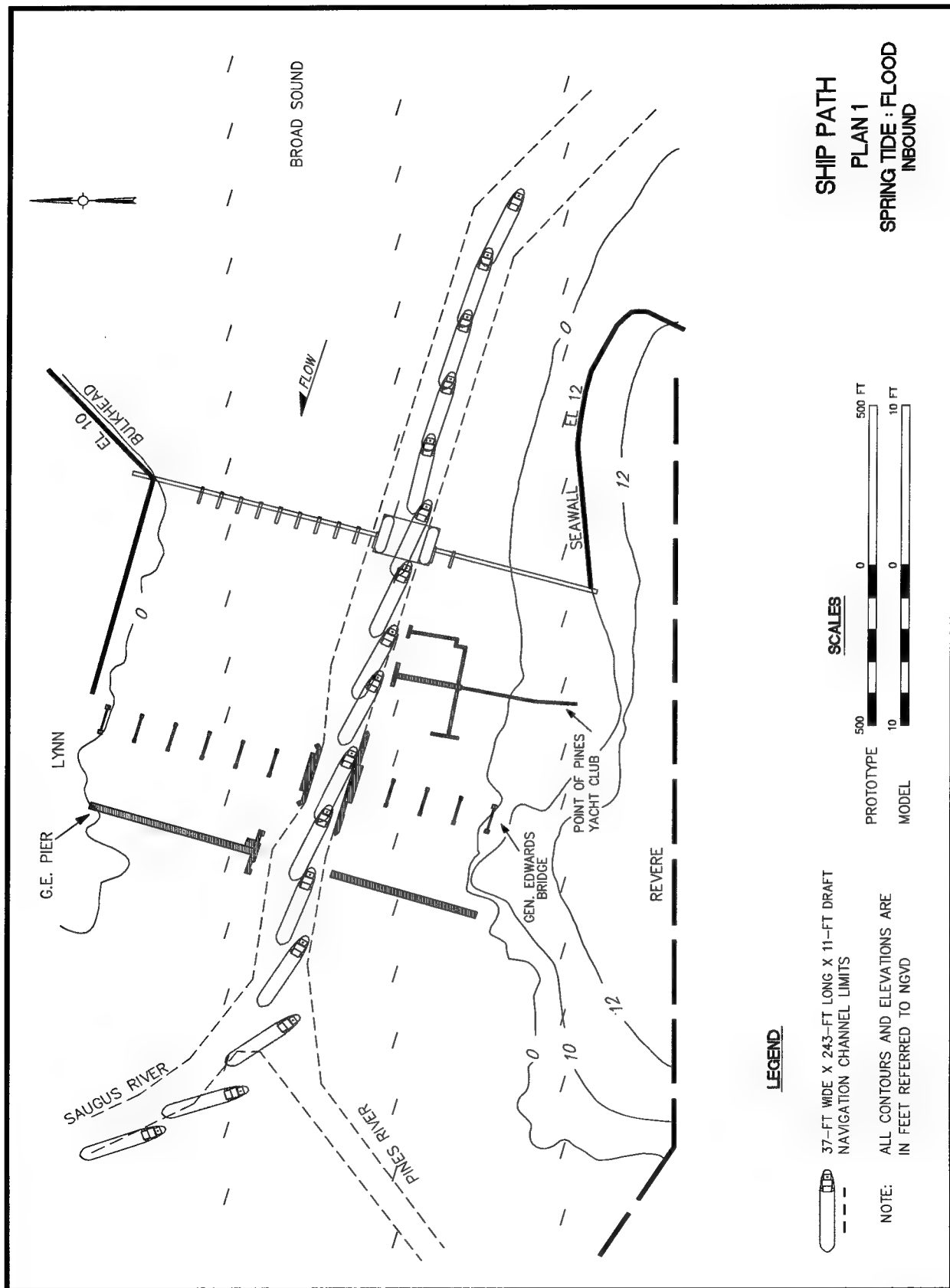


Plate 22







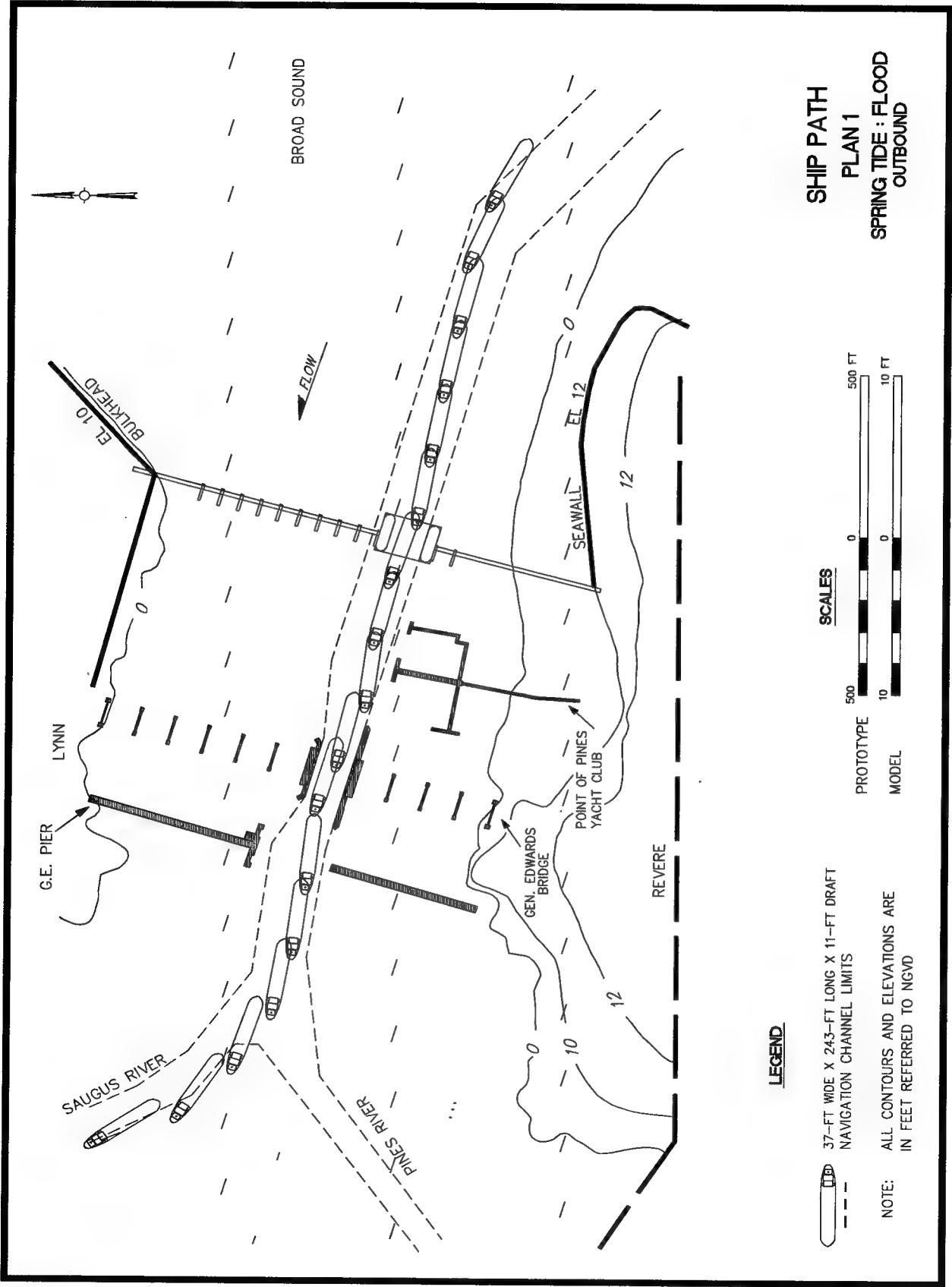
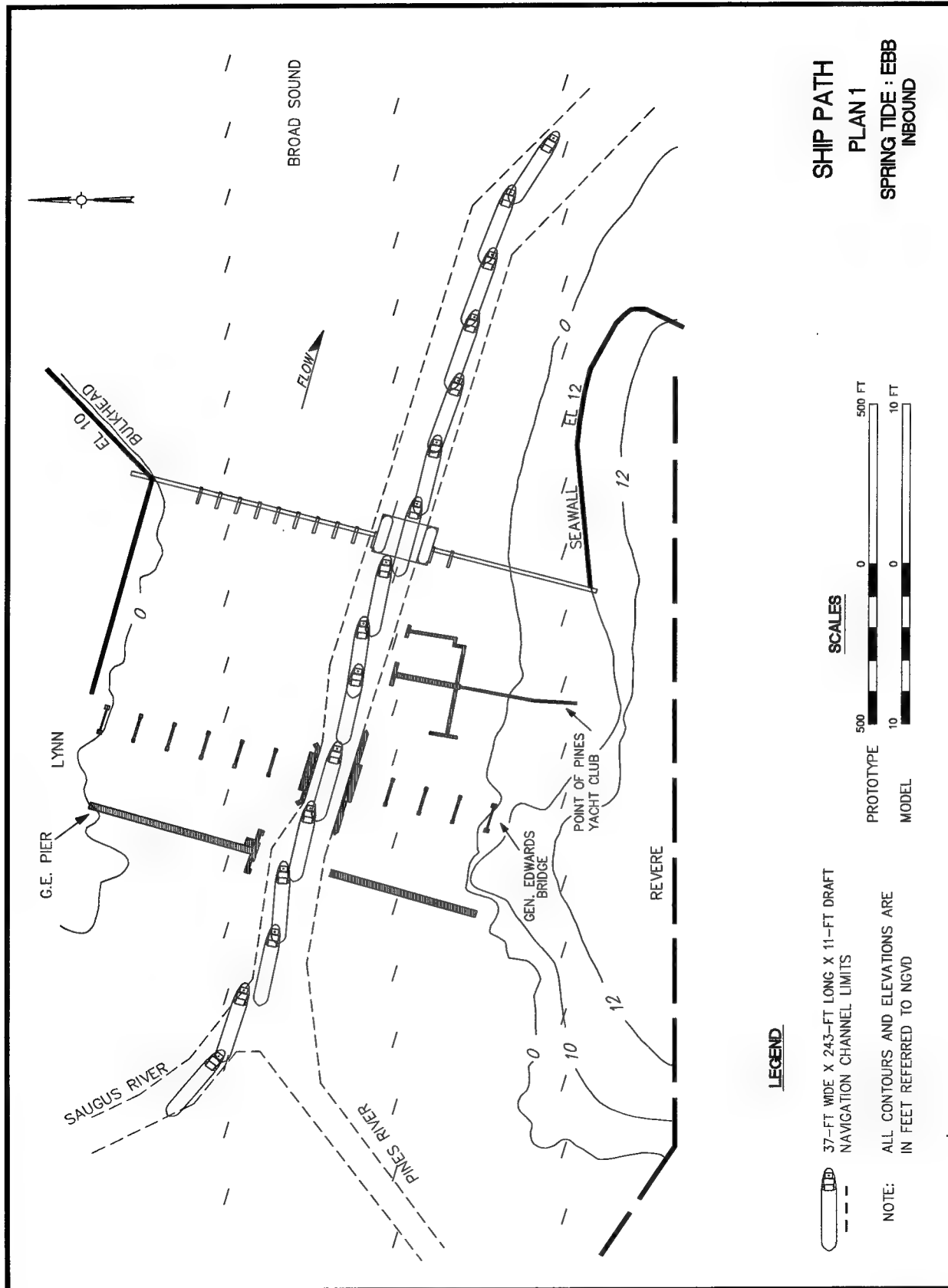


Plate 26



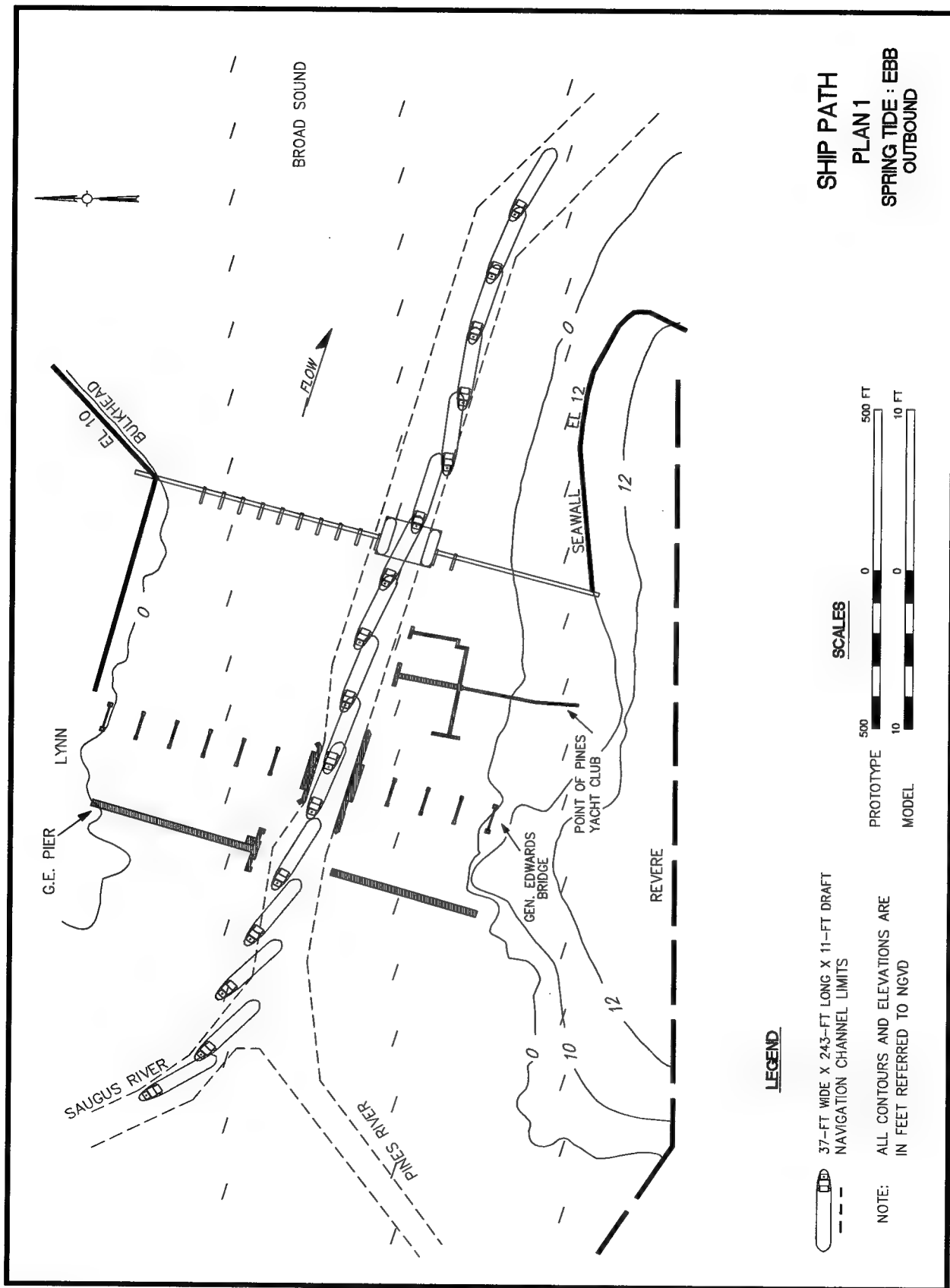
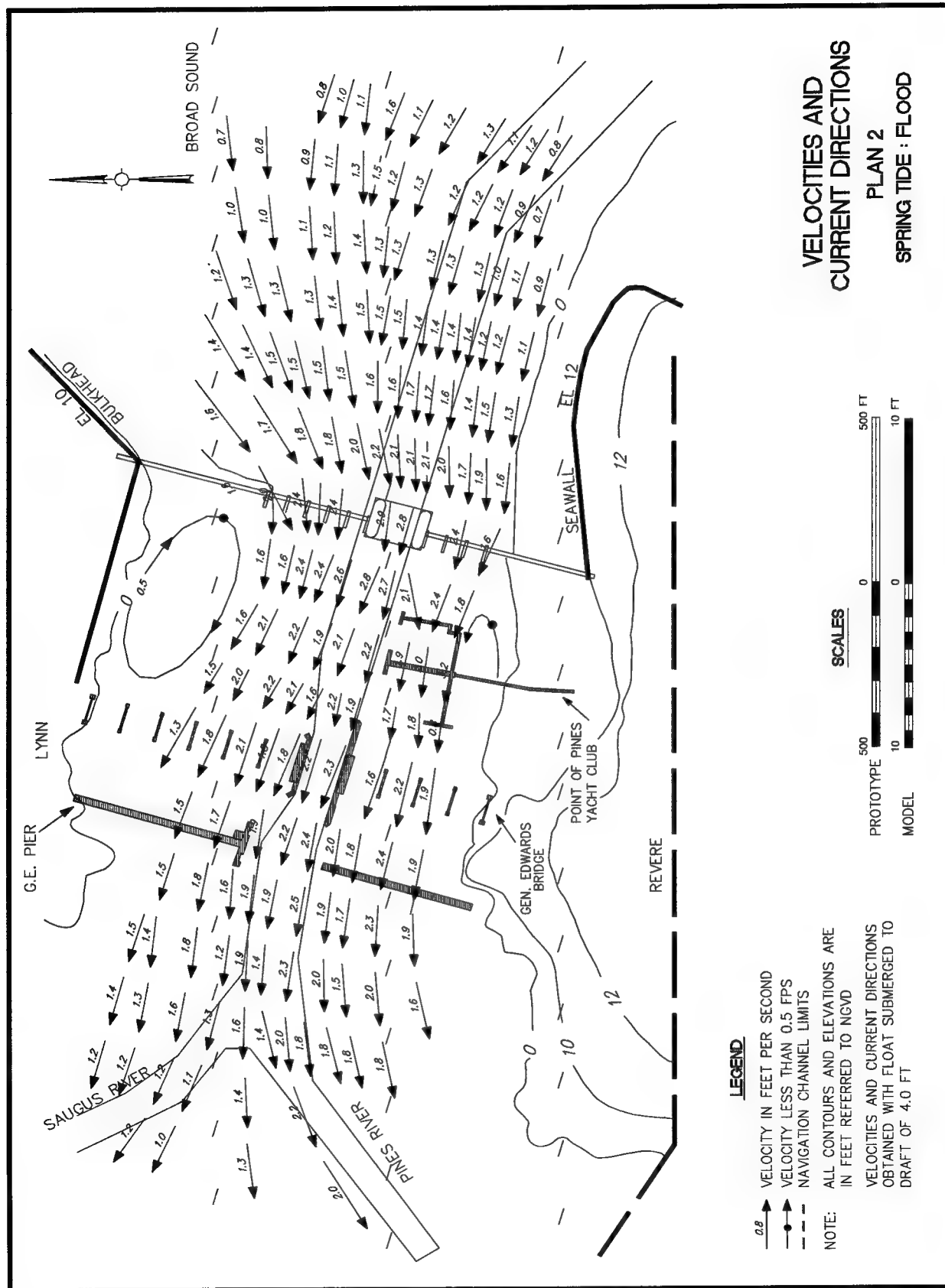


Plate 28



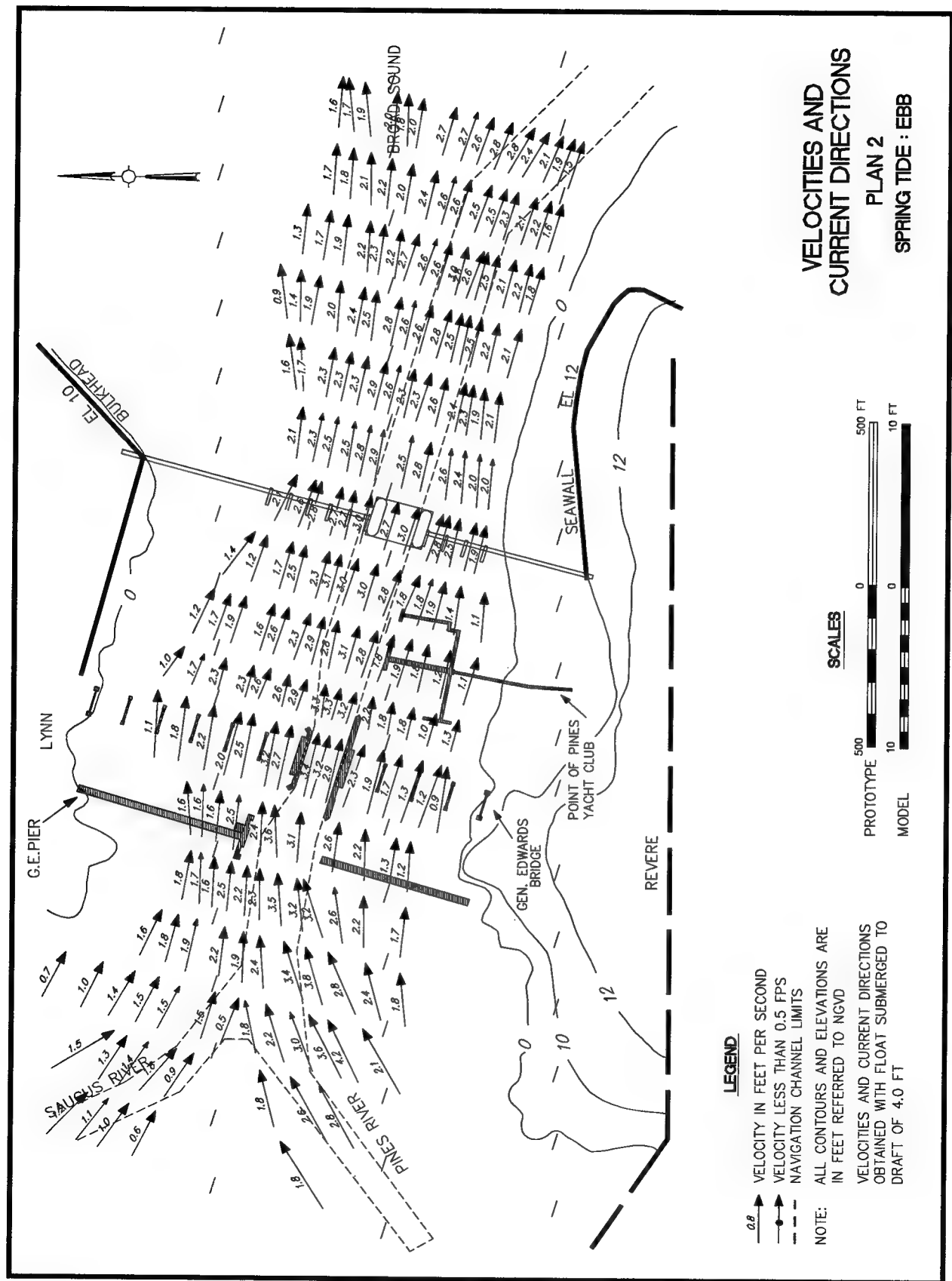
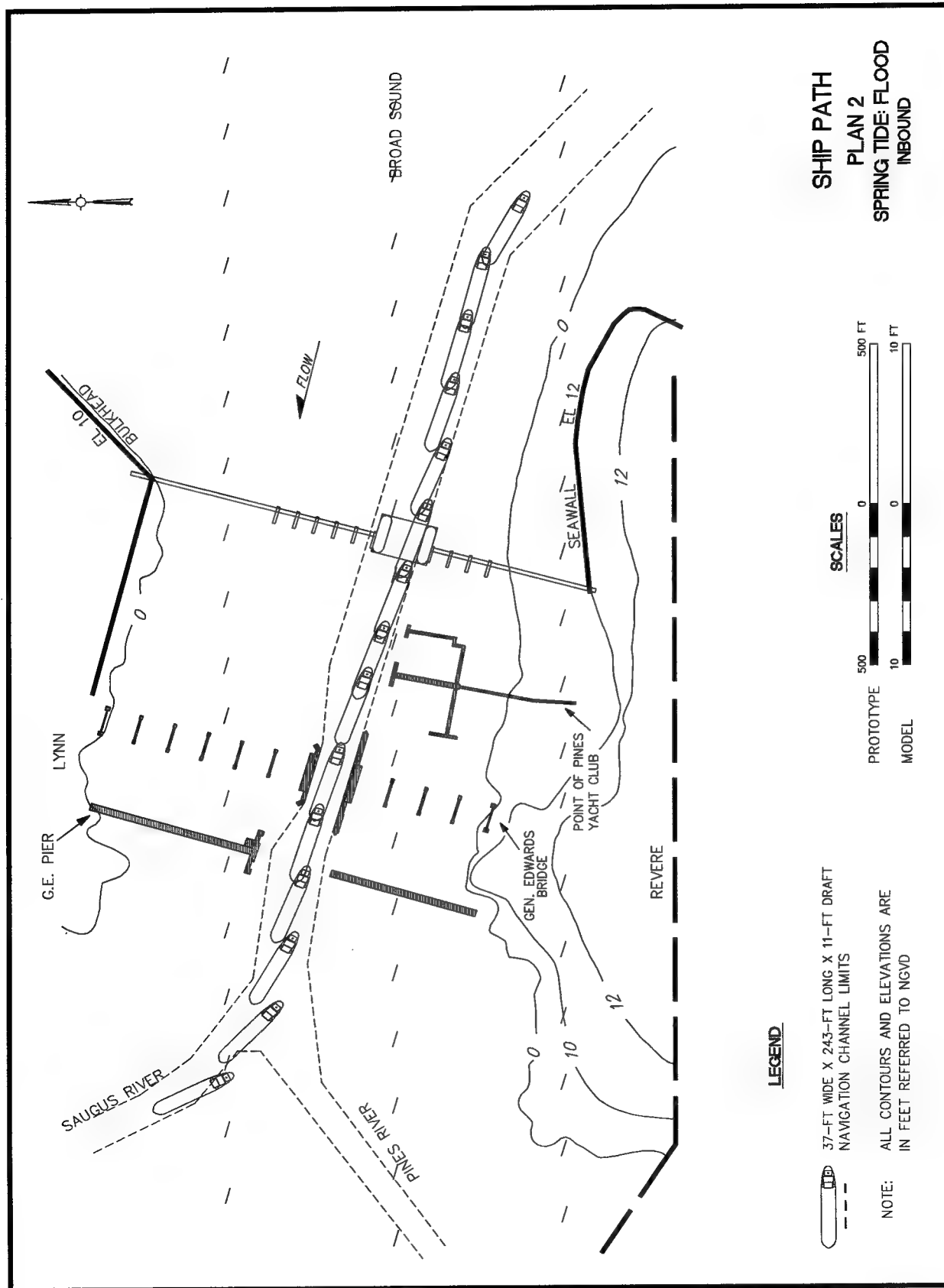


Plate 30



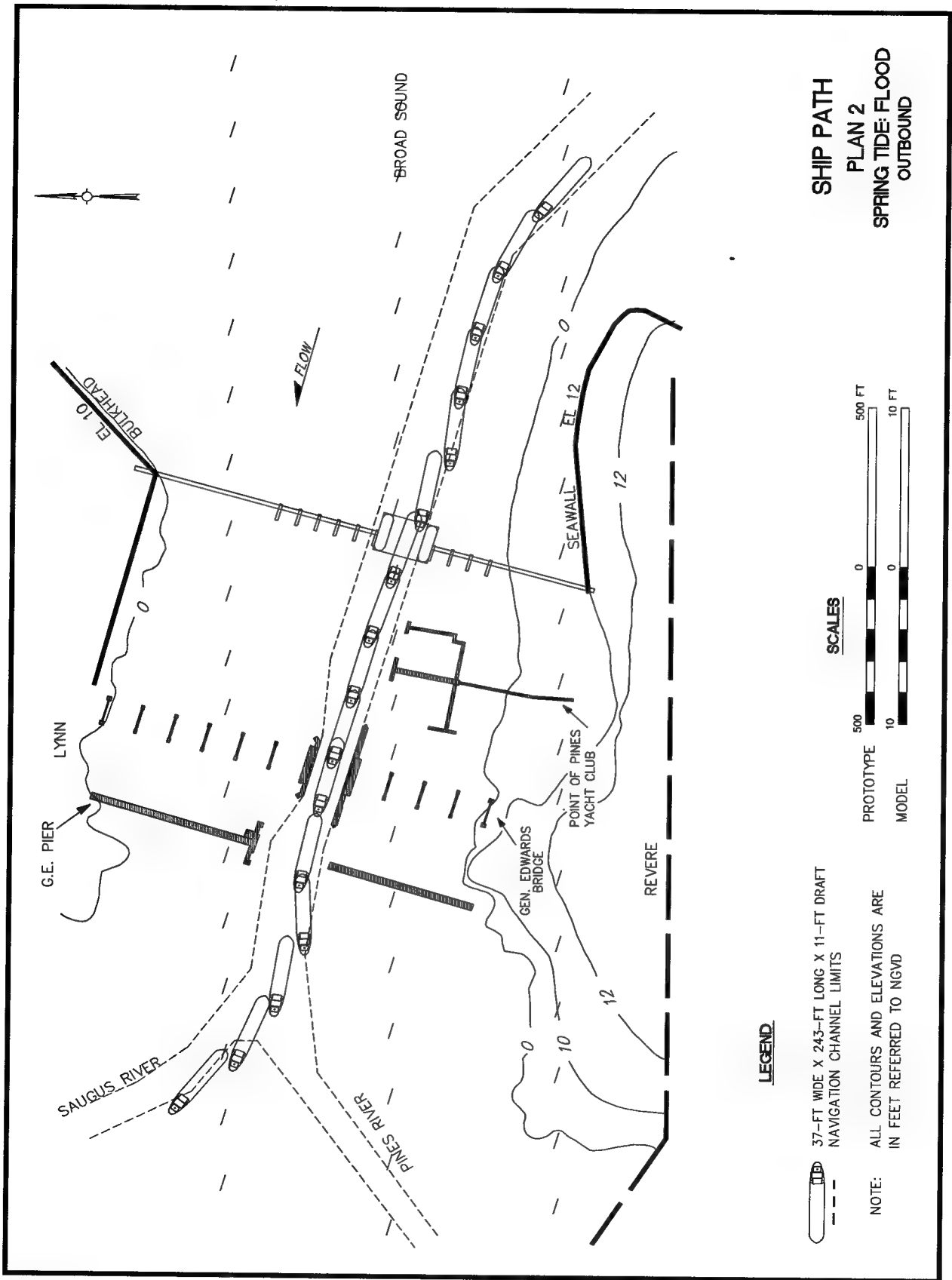
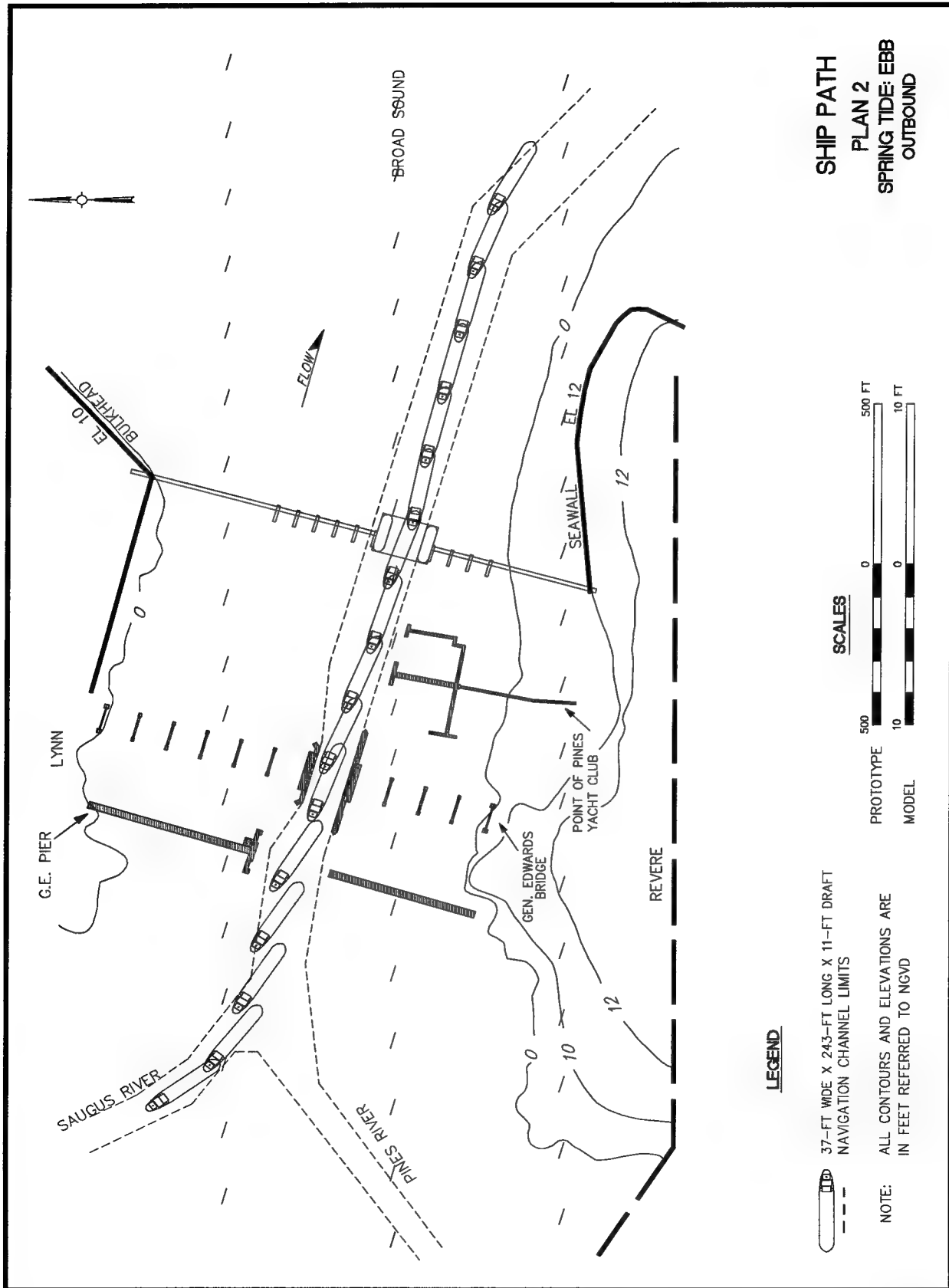


Plate 32



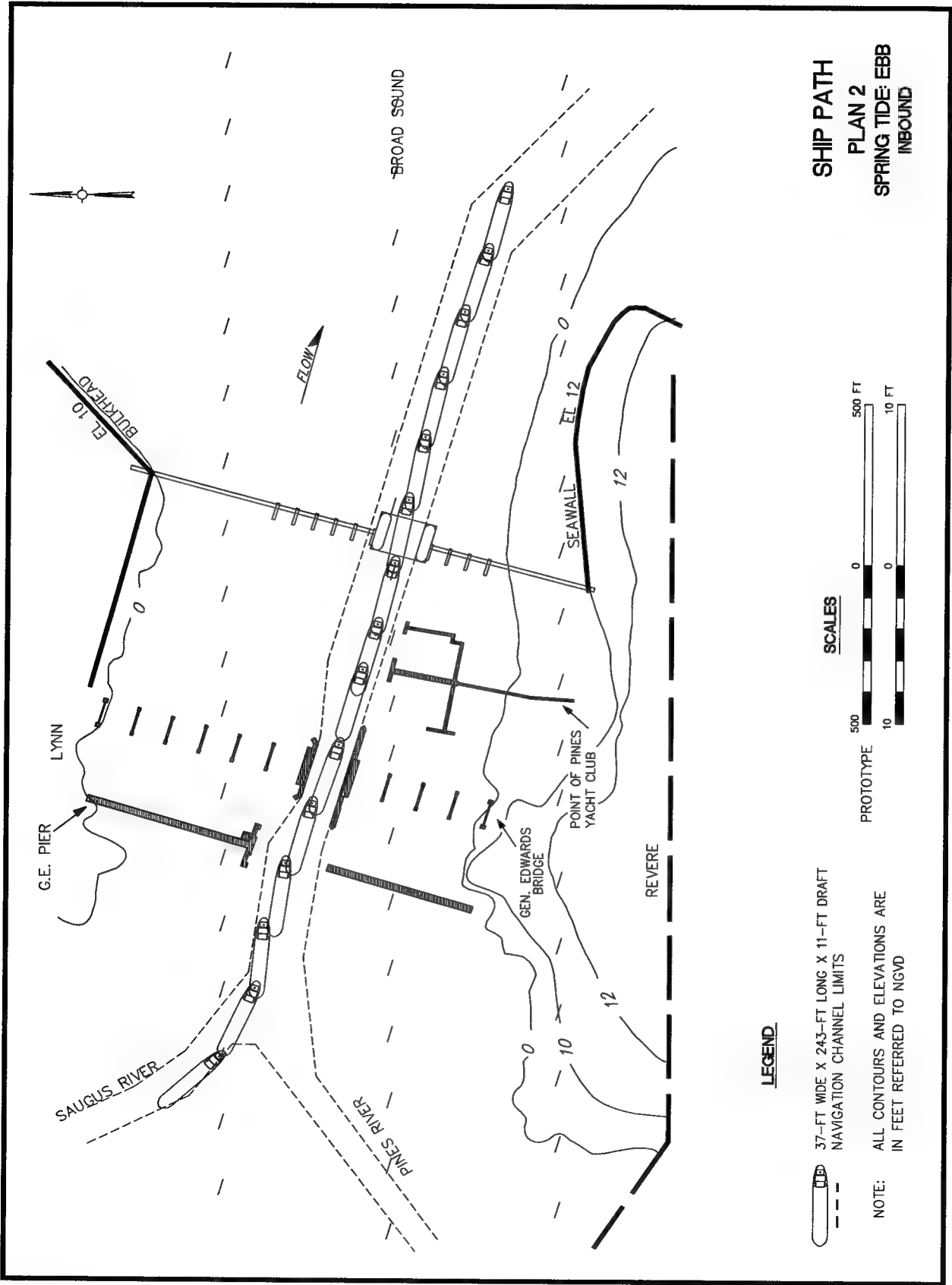
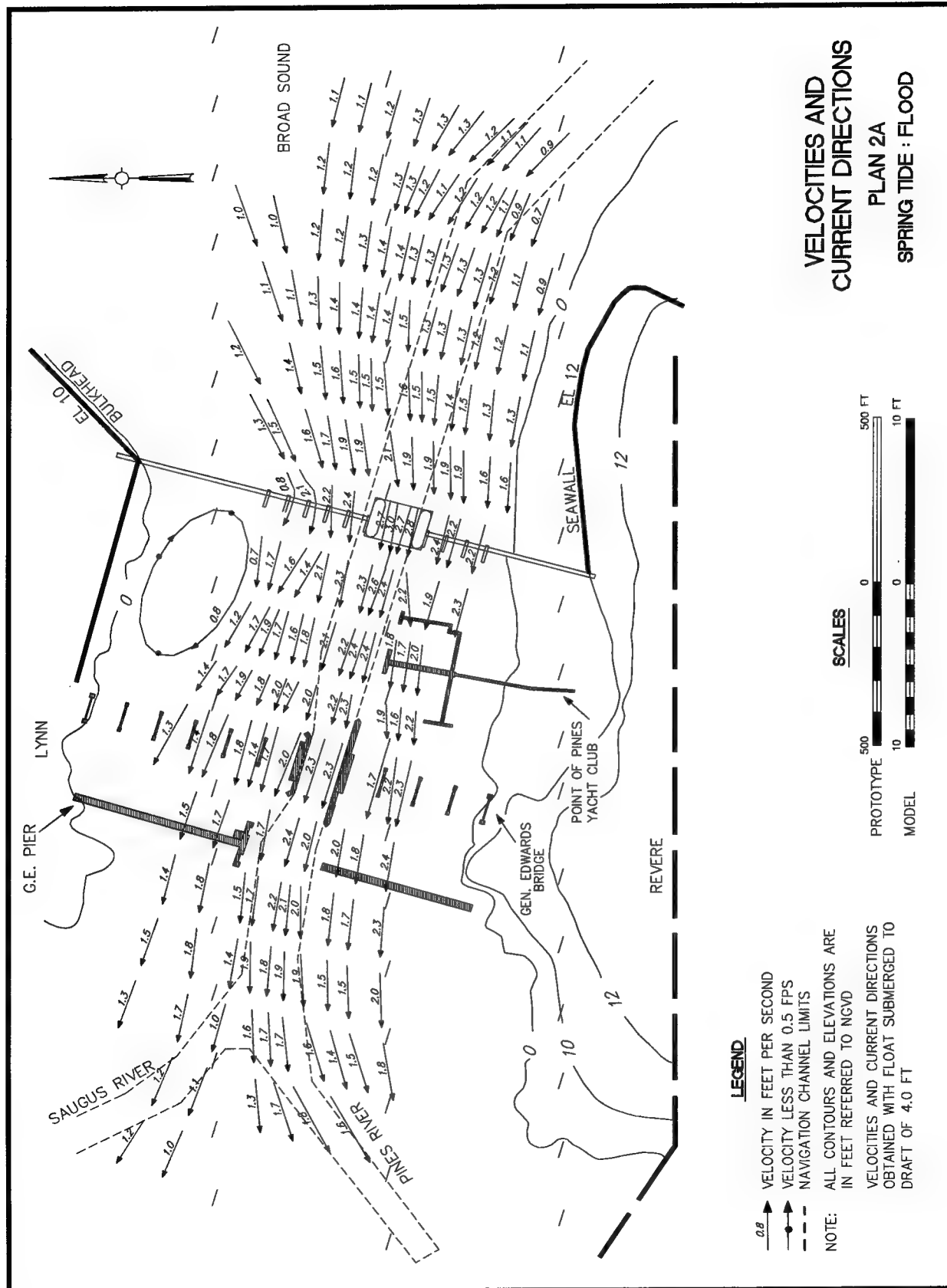
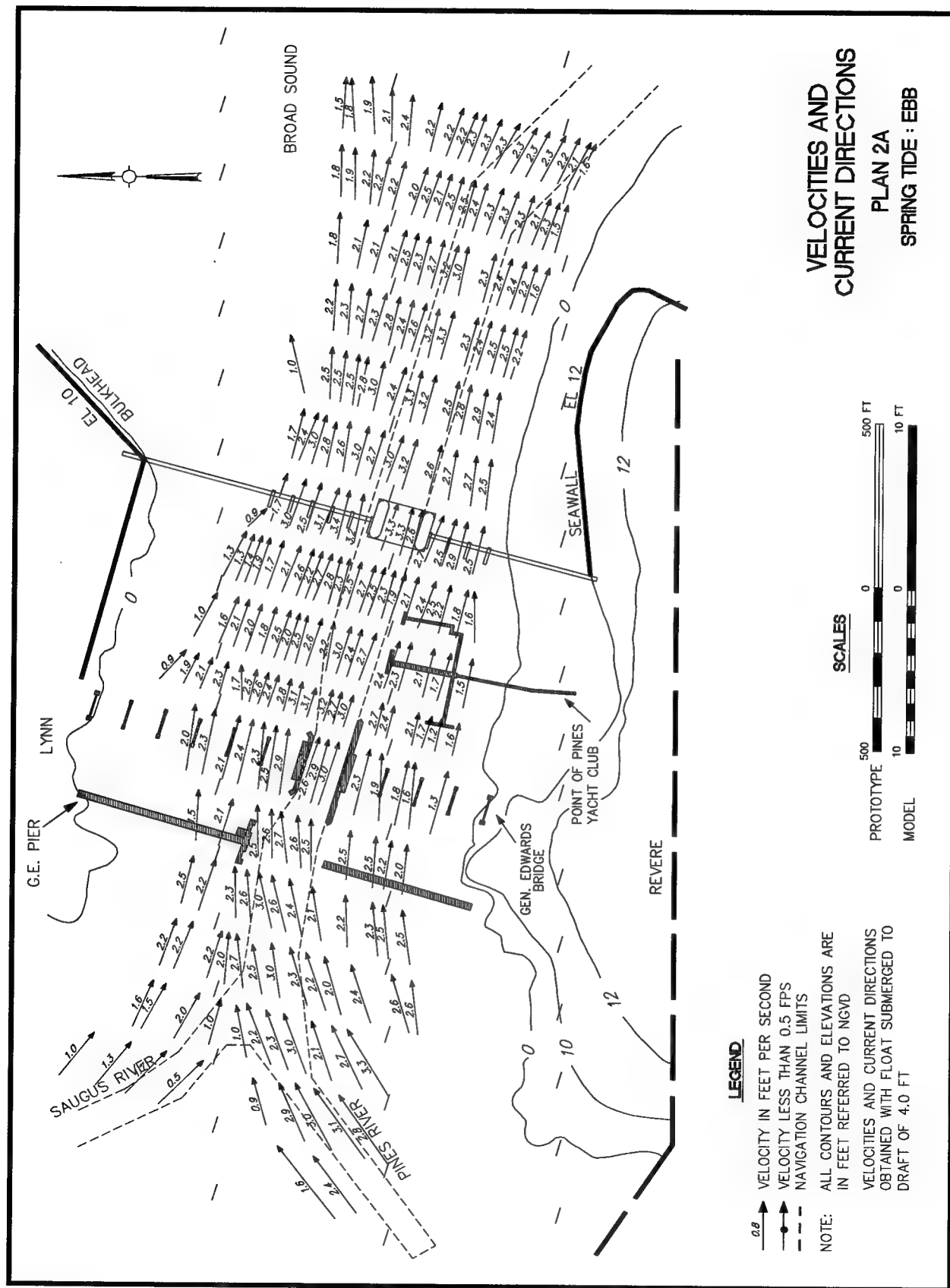
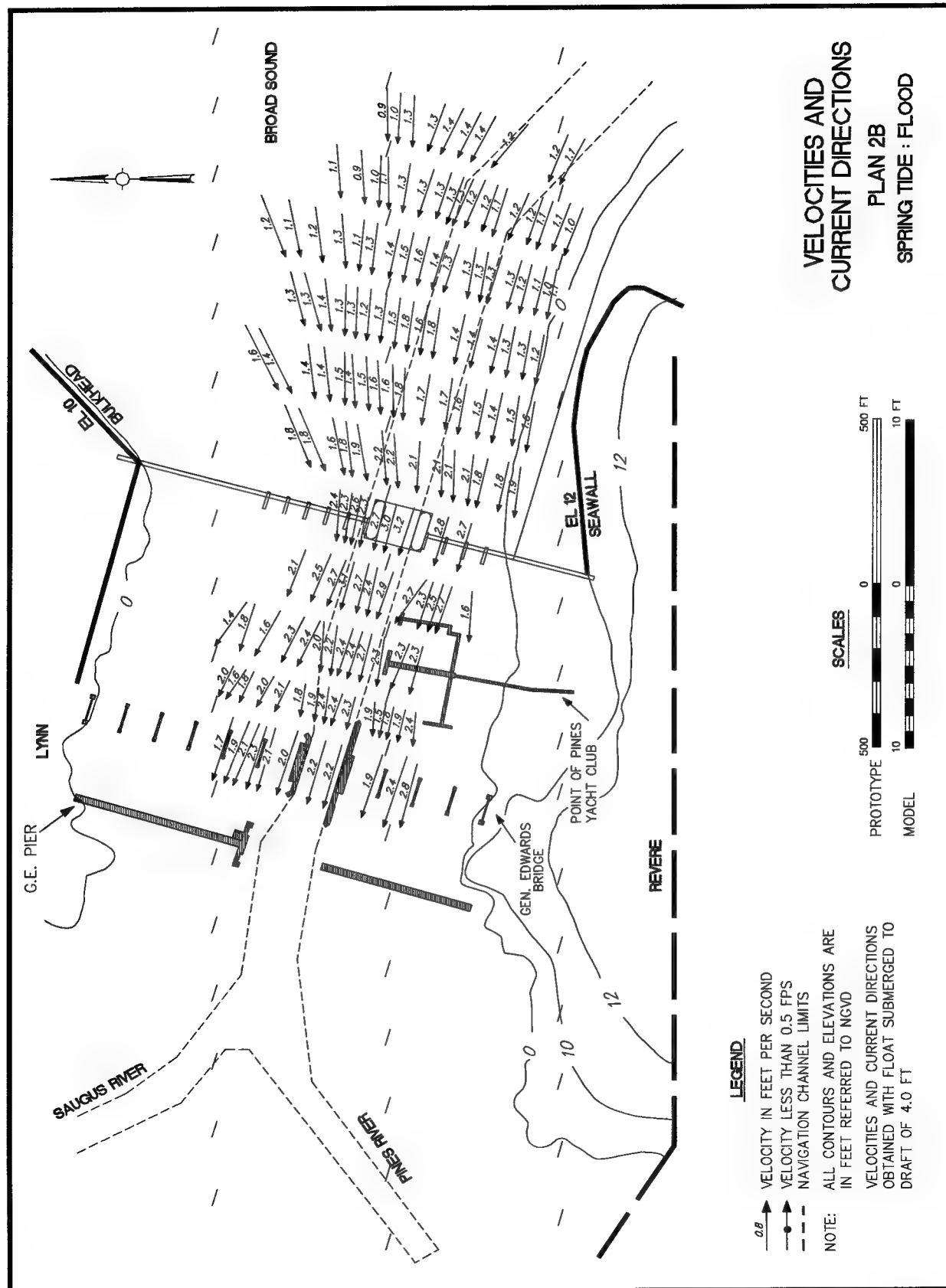


Plate 34







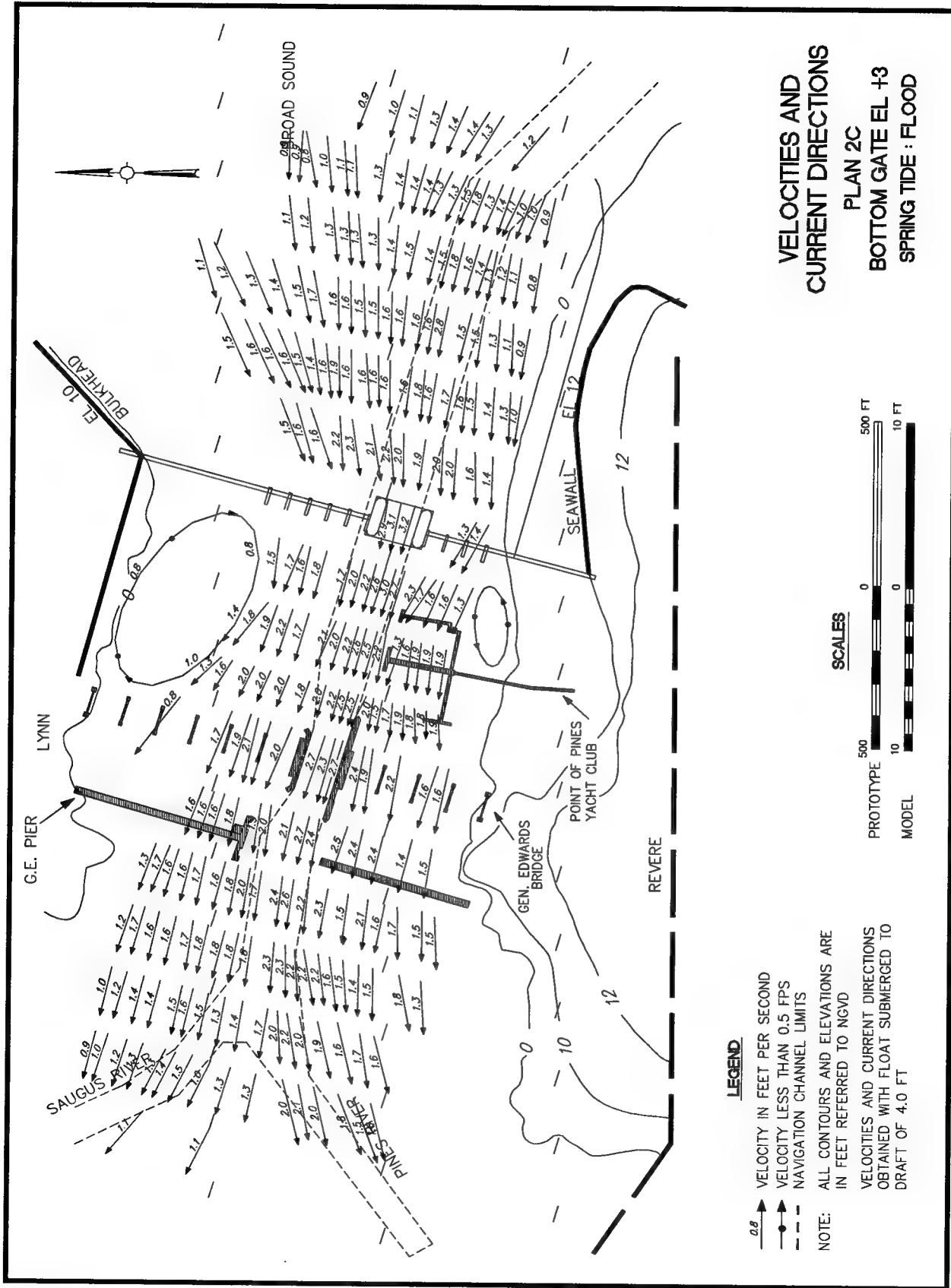
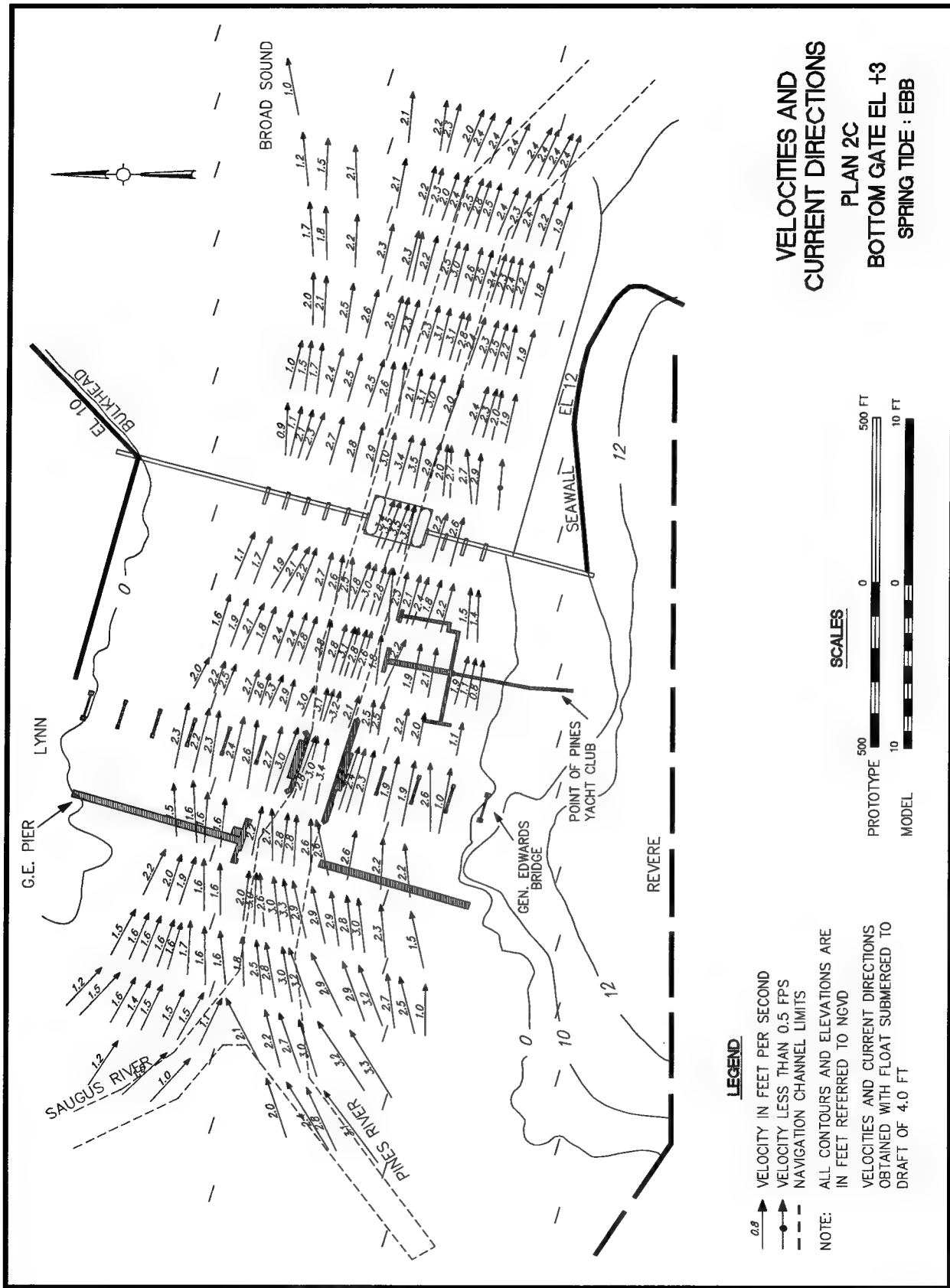


Plate 38



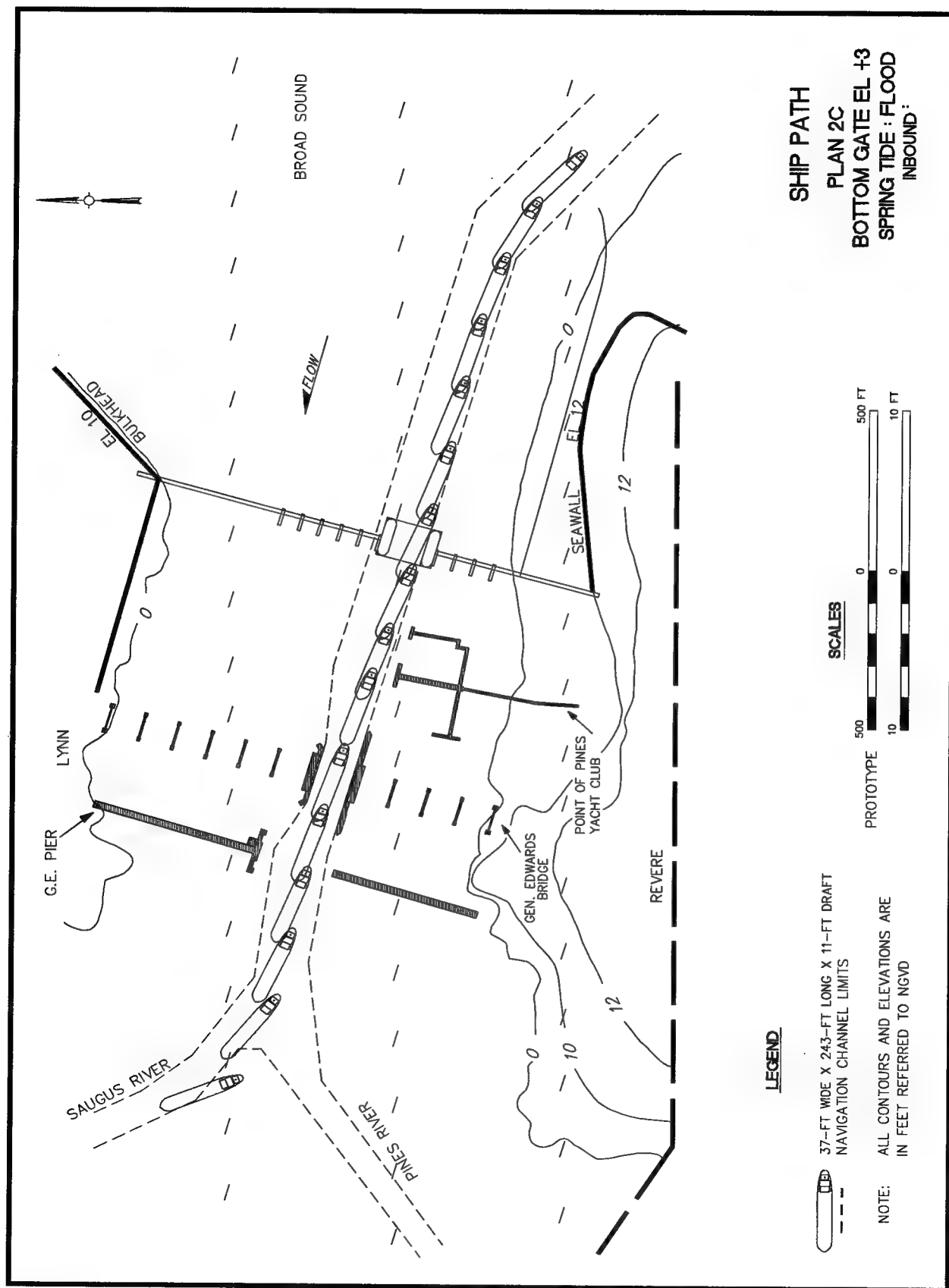
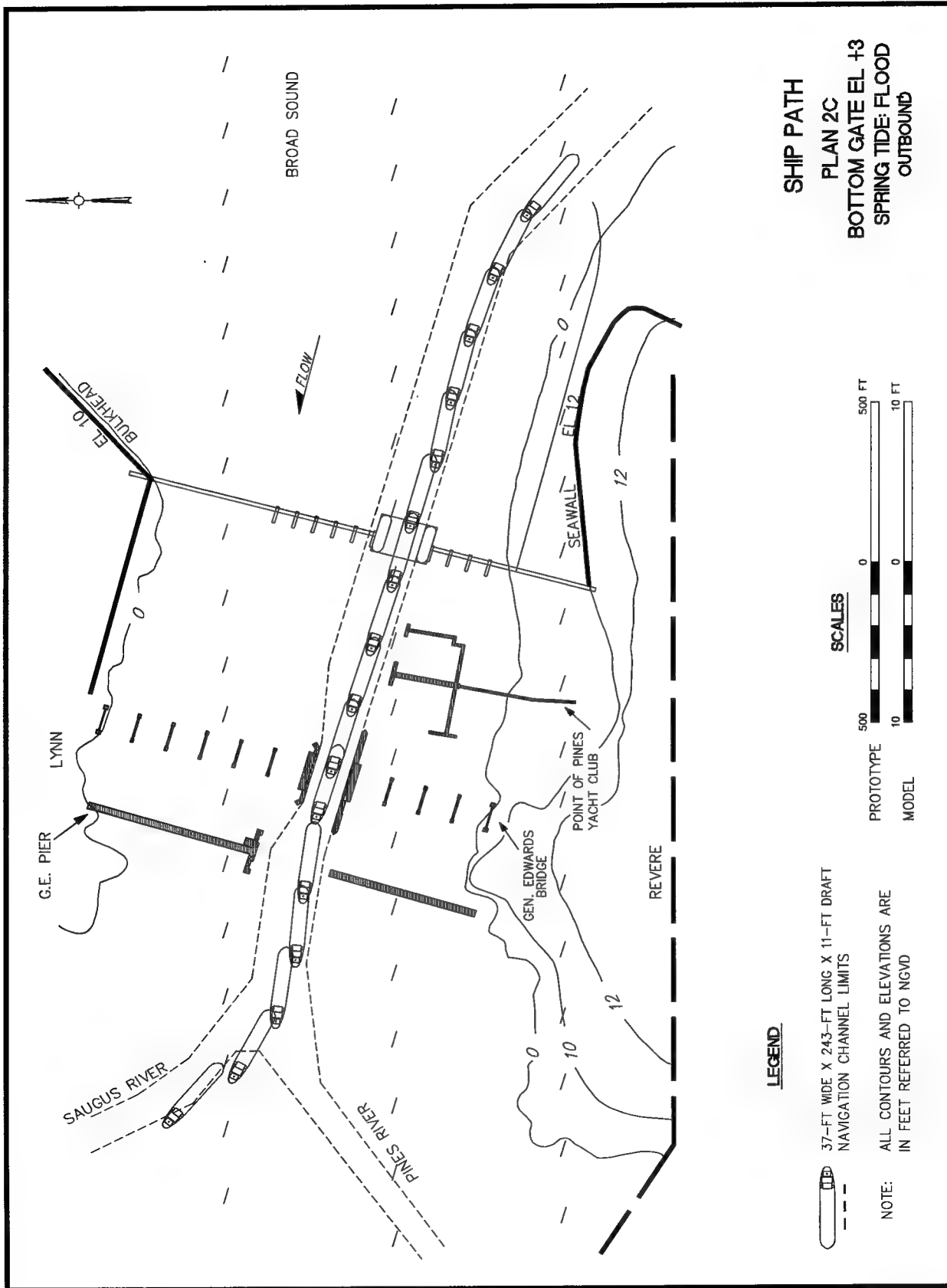


Plate 40



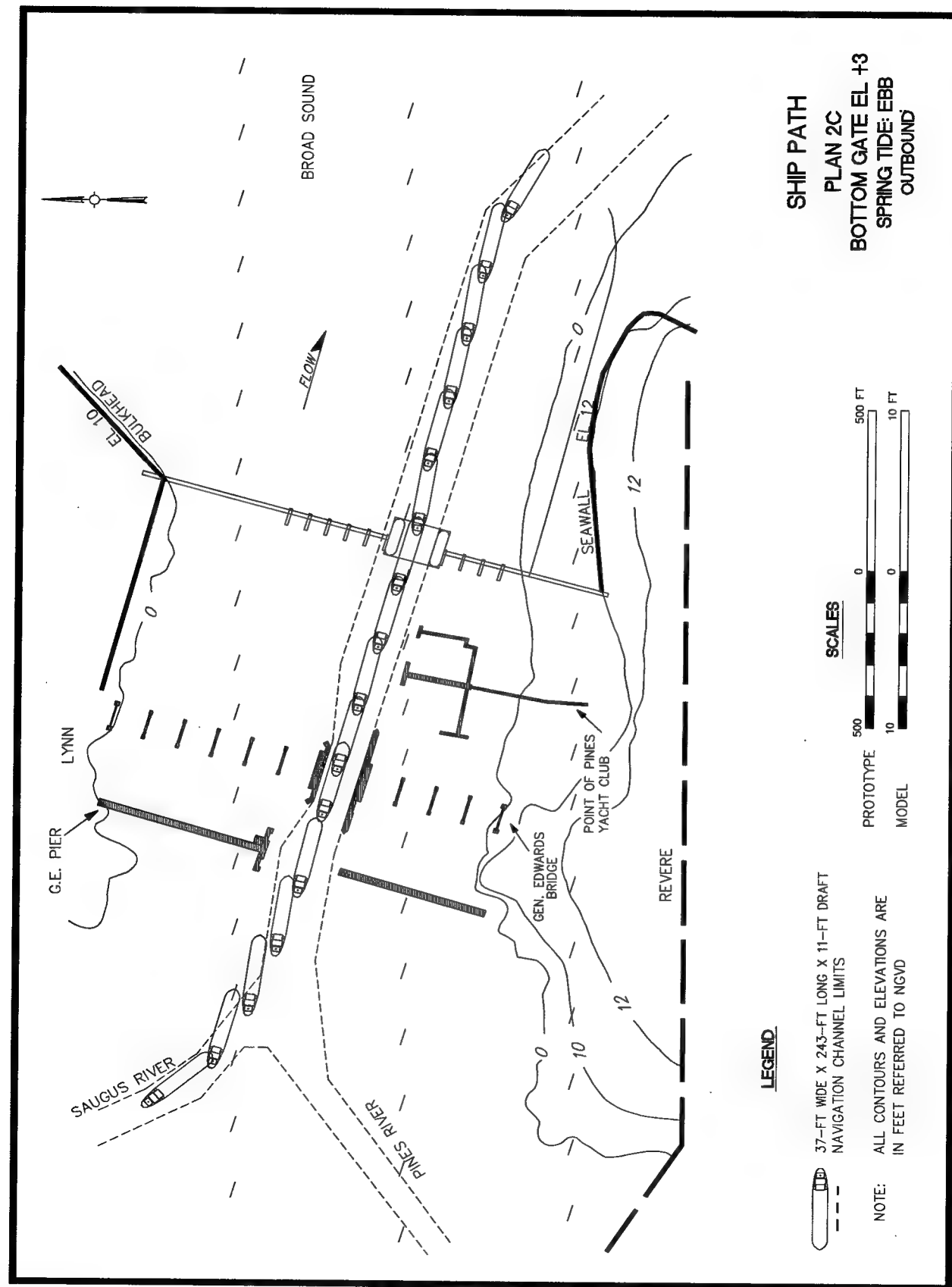
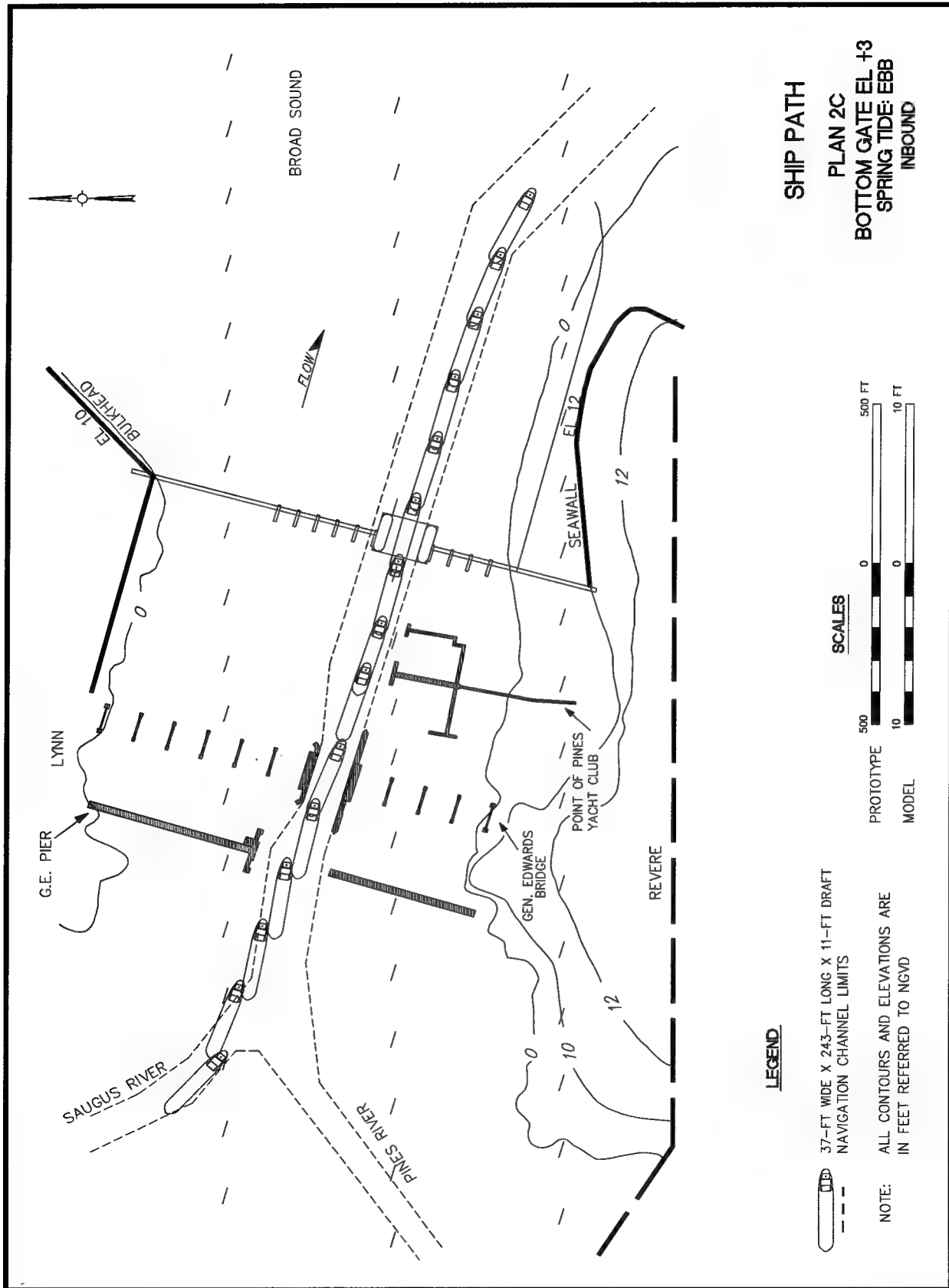


Plate 42



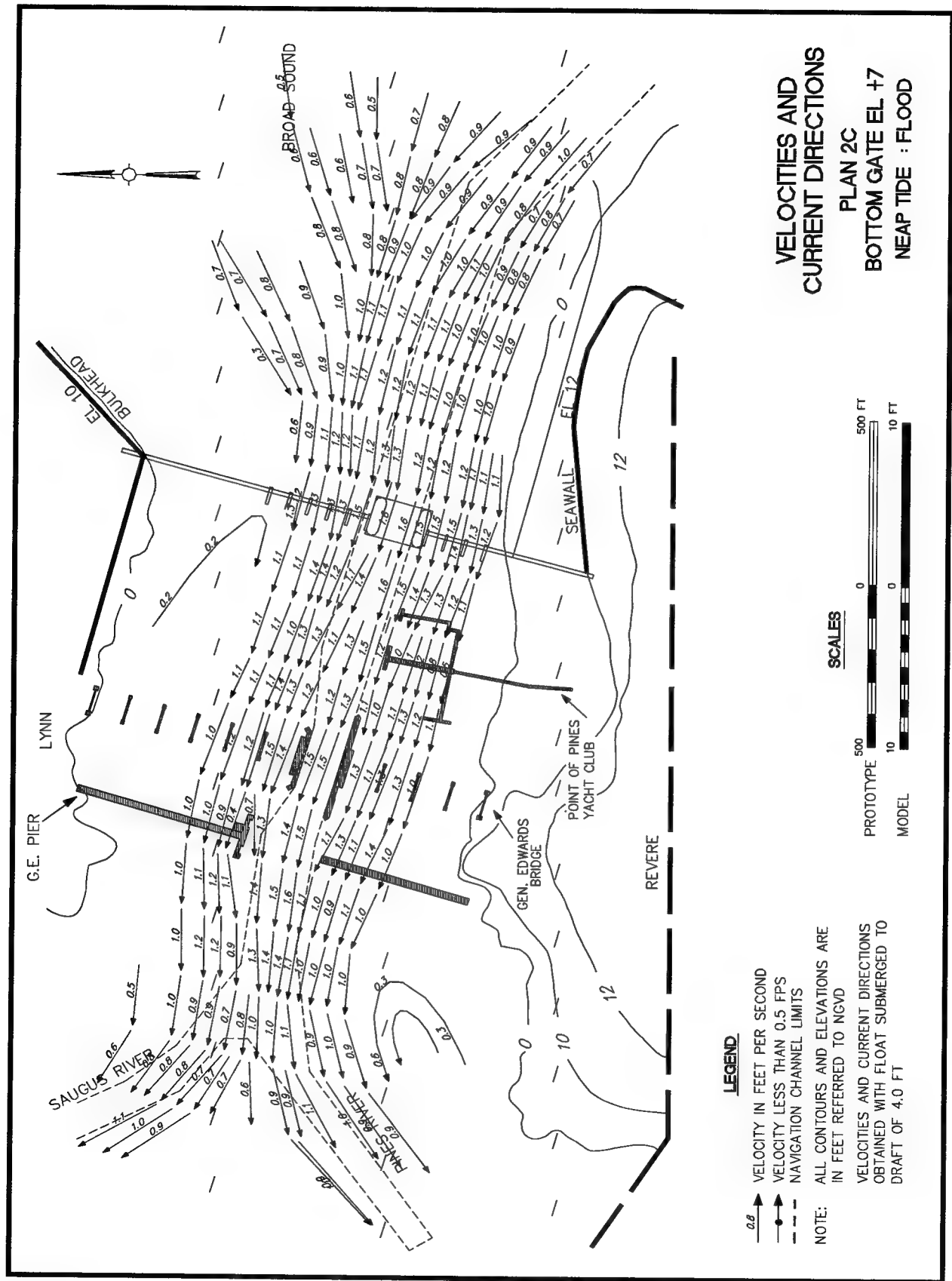
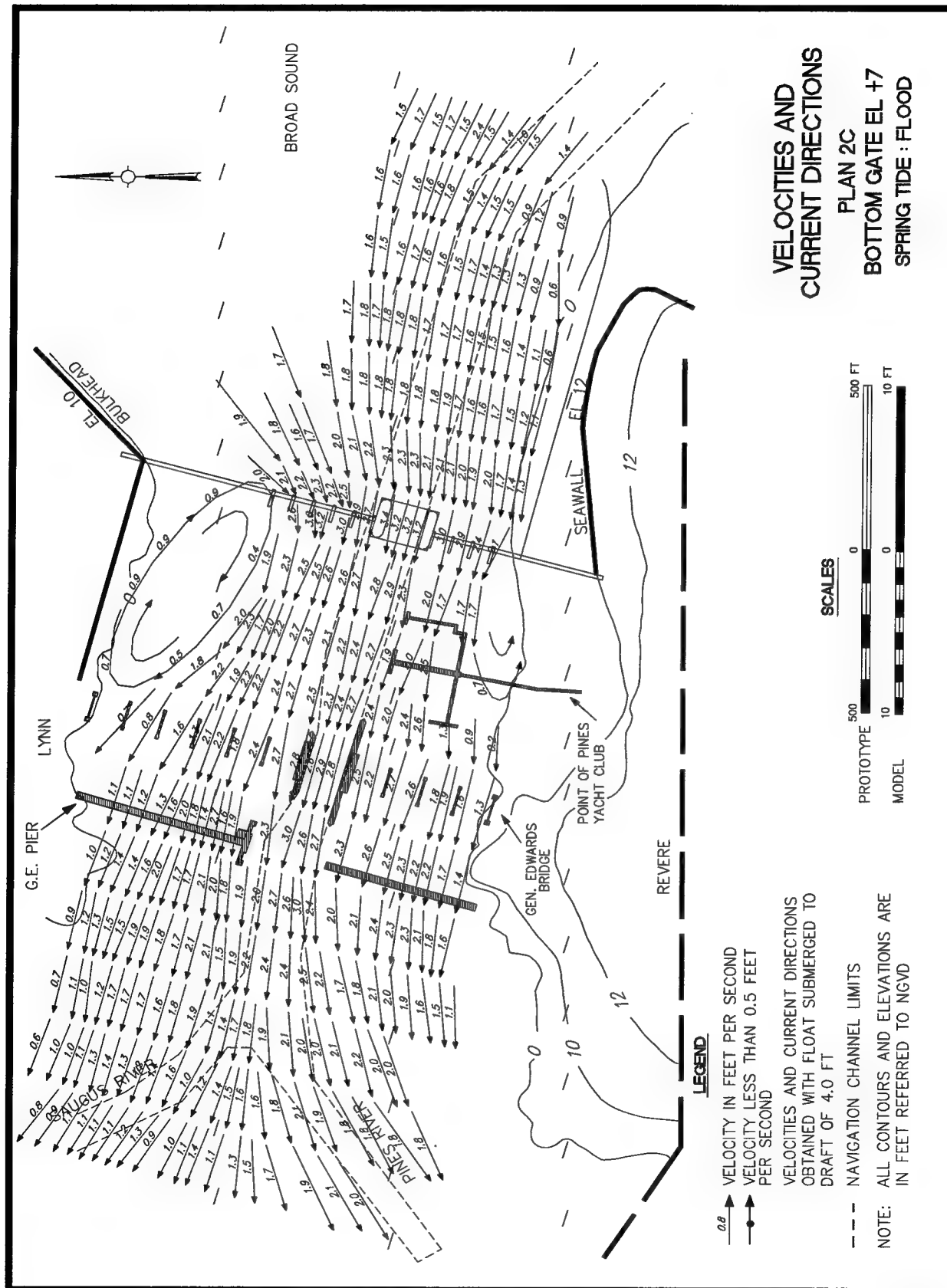
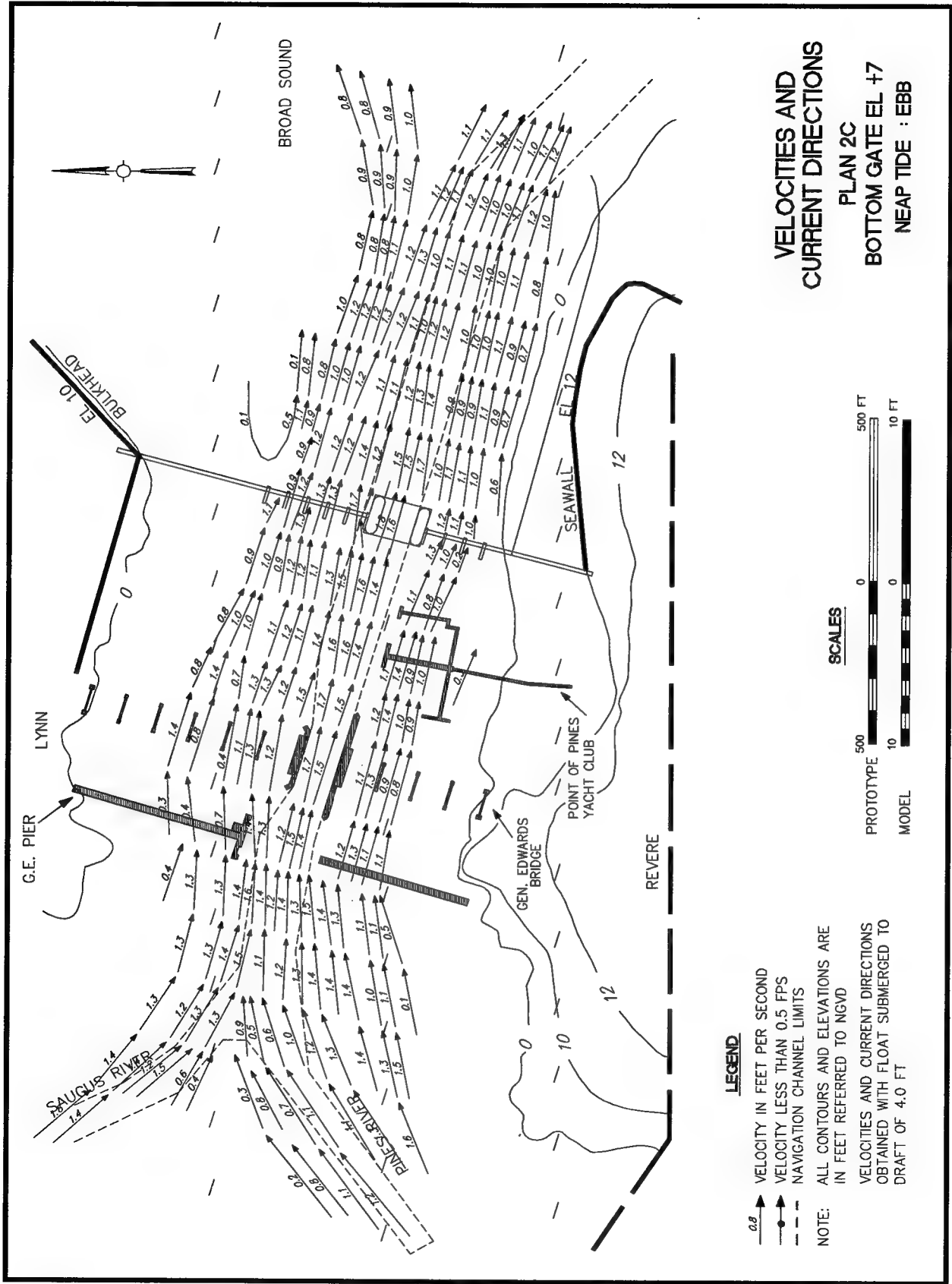
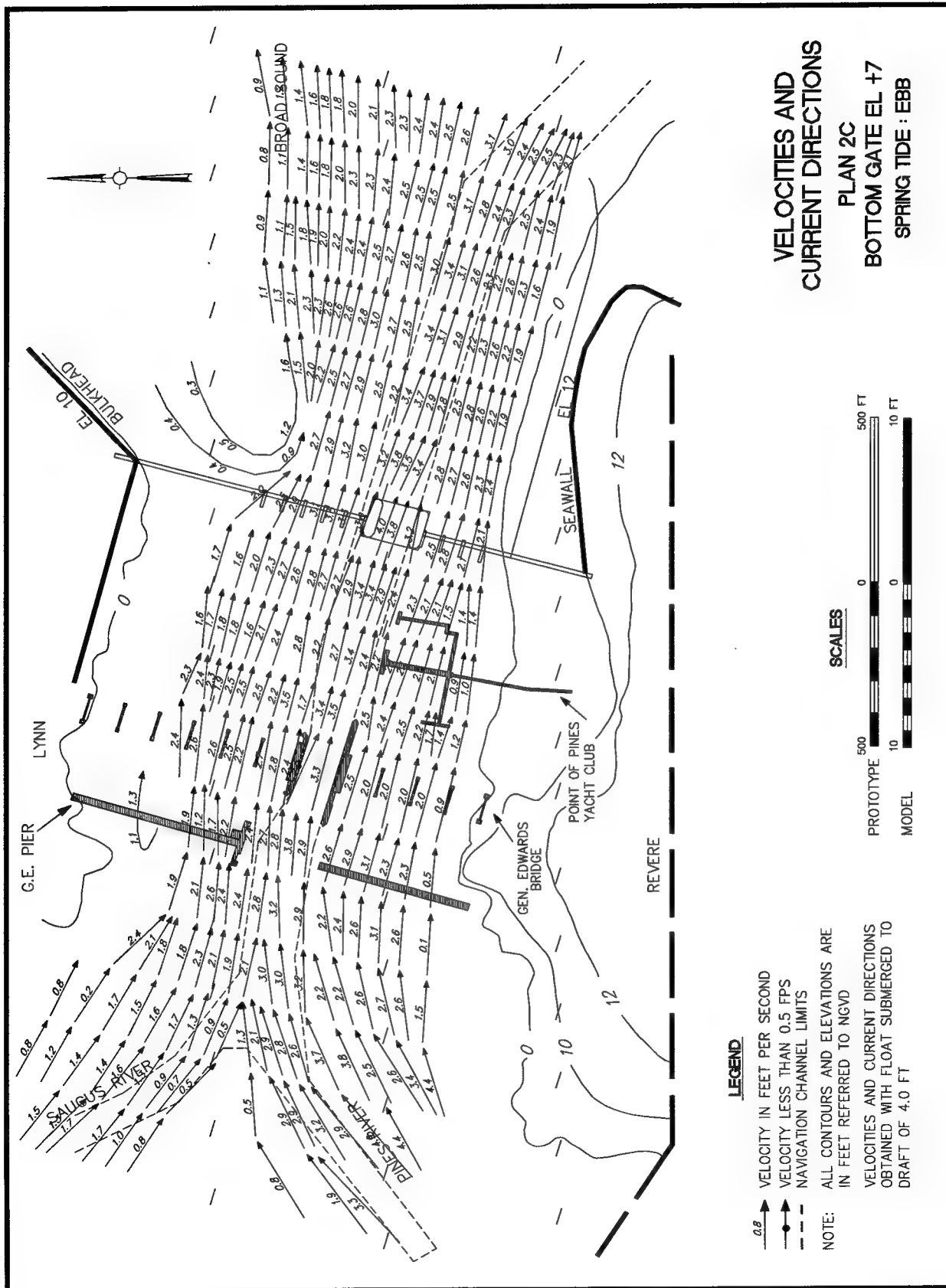


Plate 44







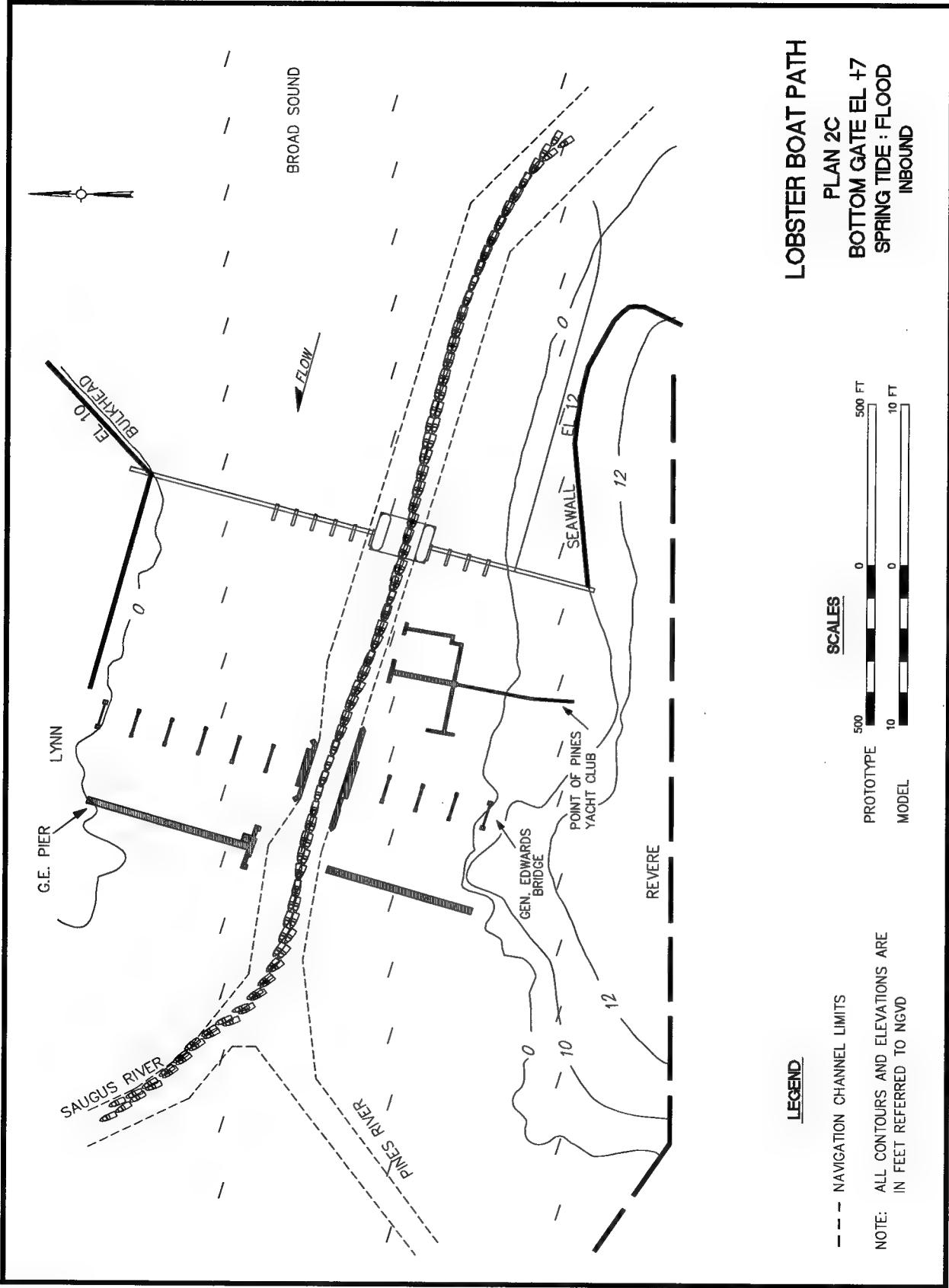
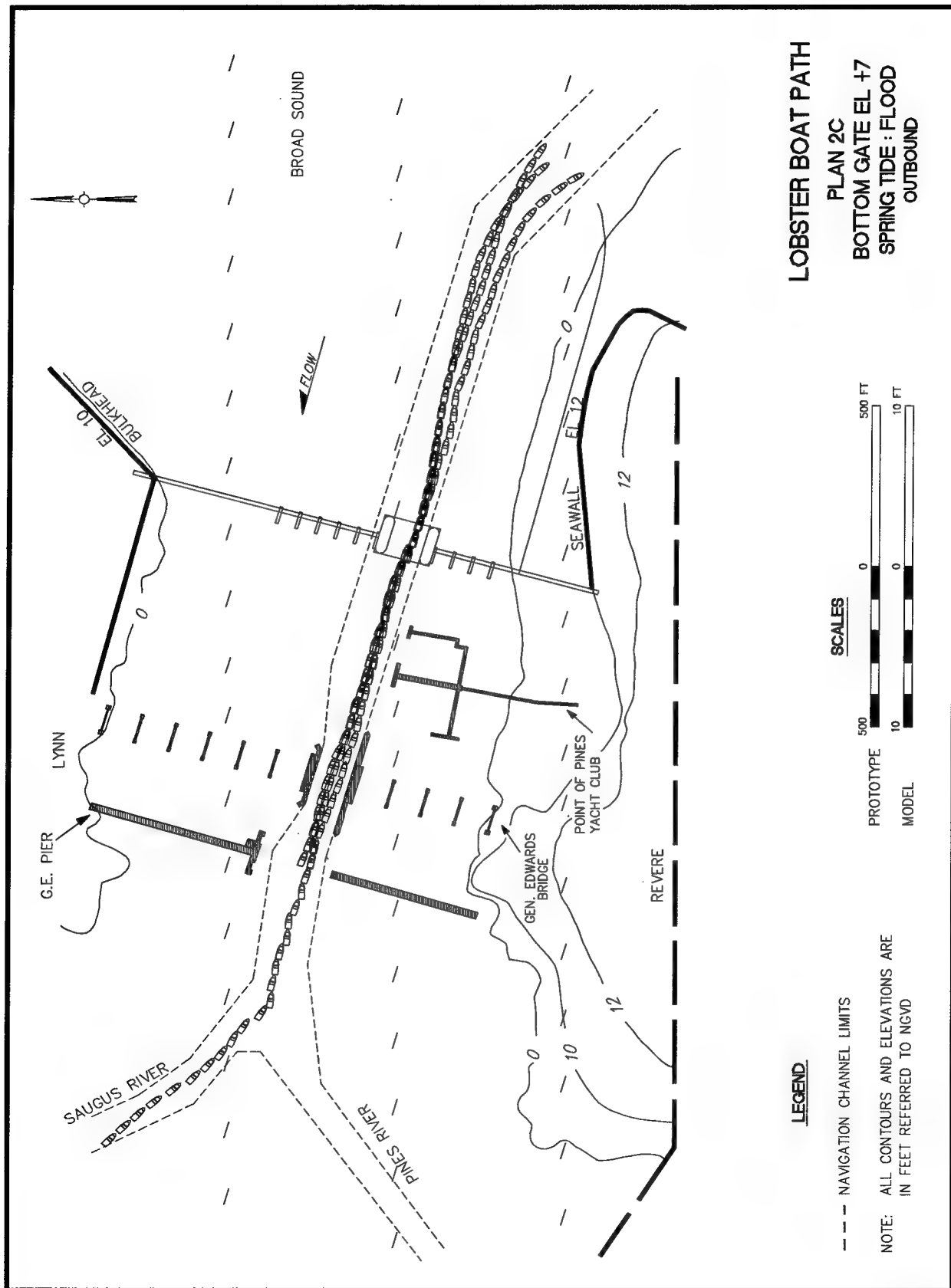


Plate 48



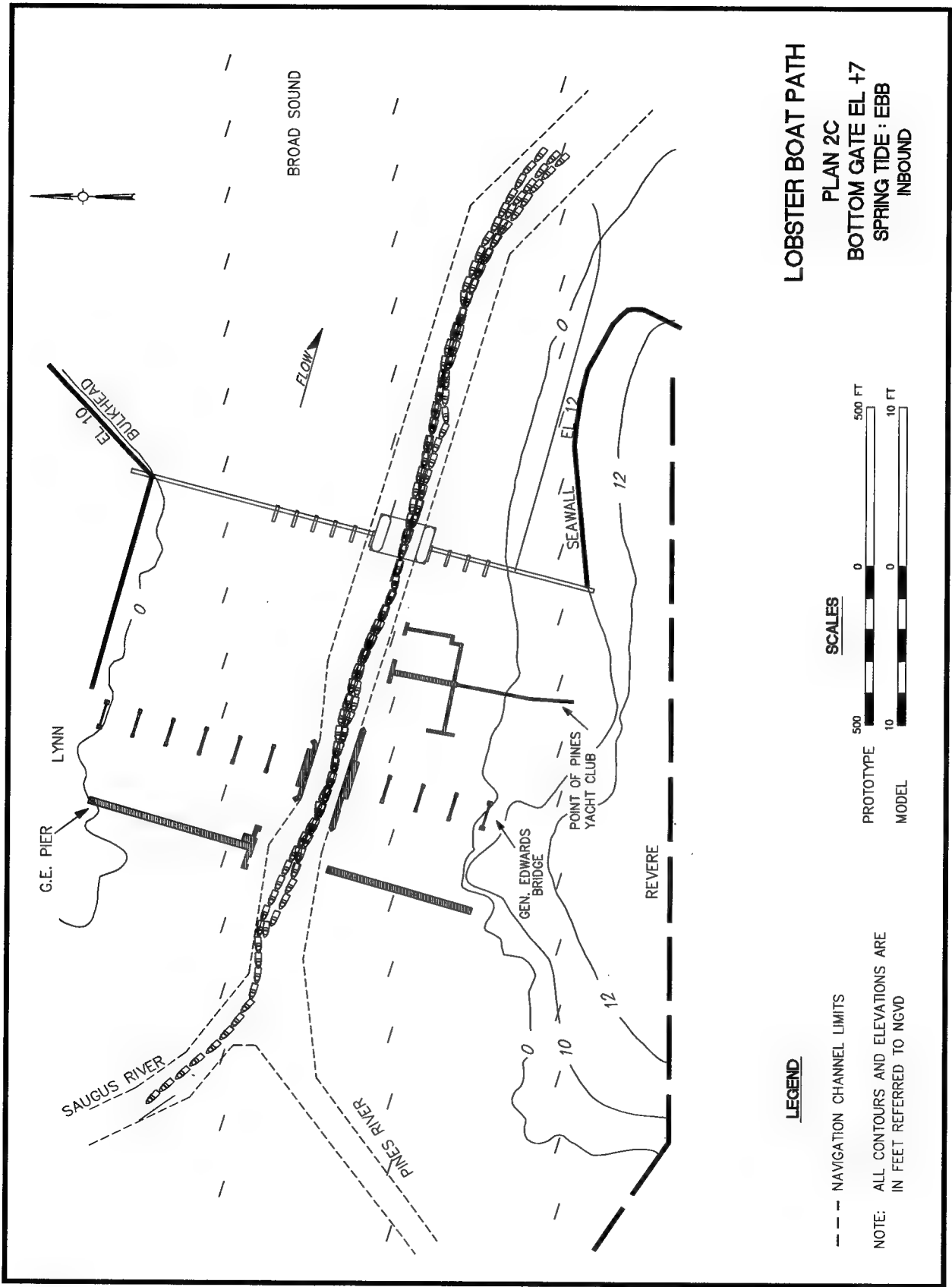
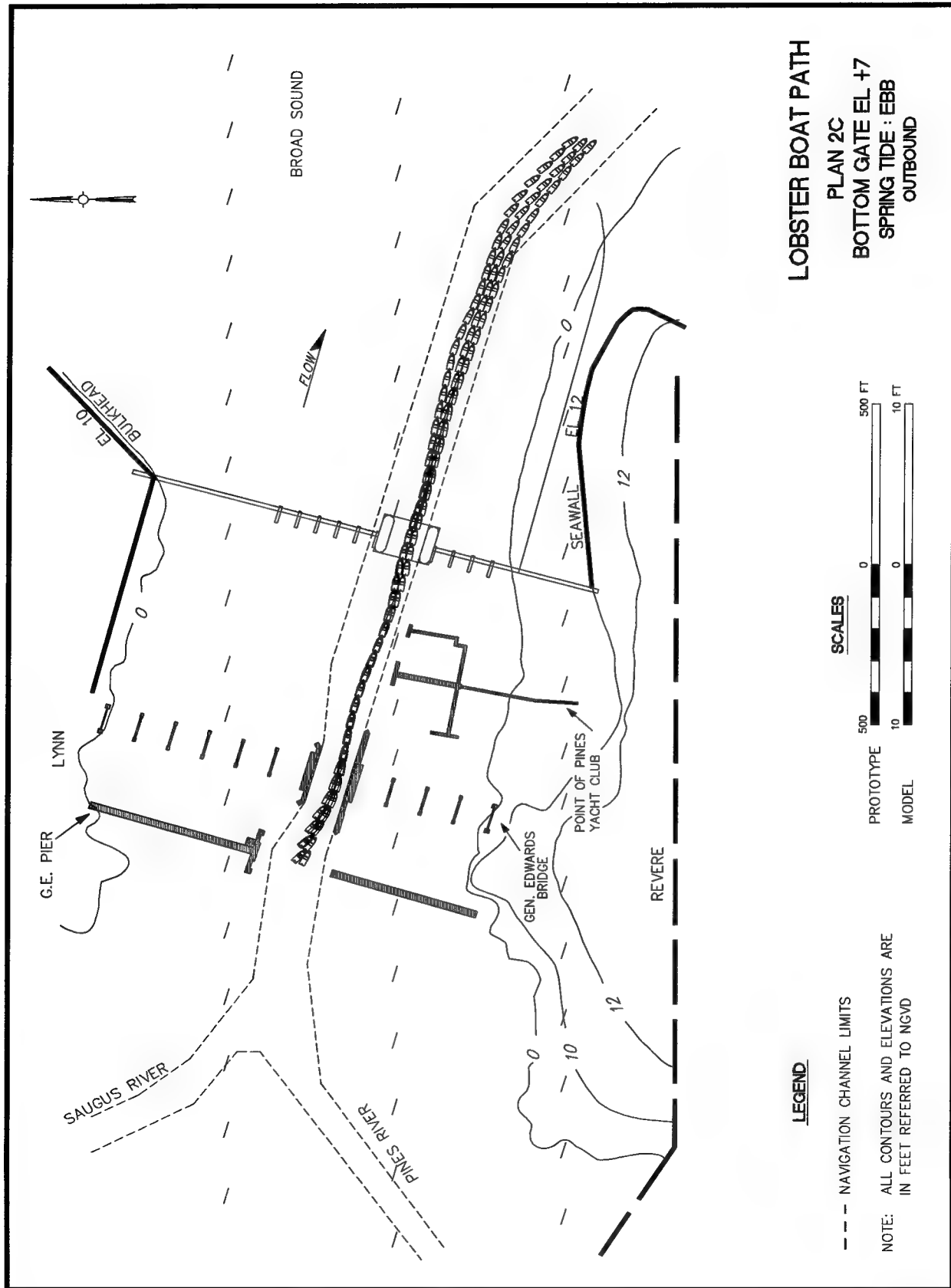
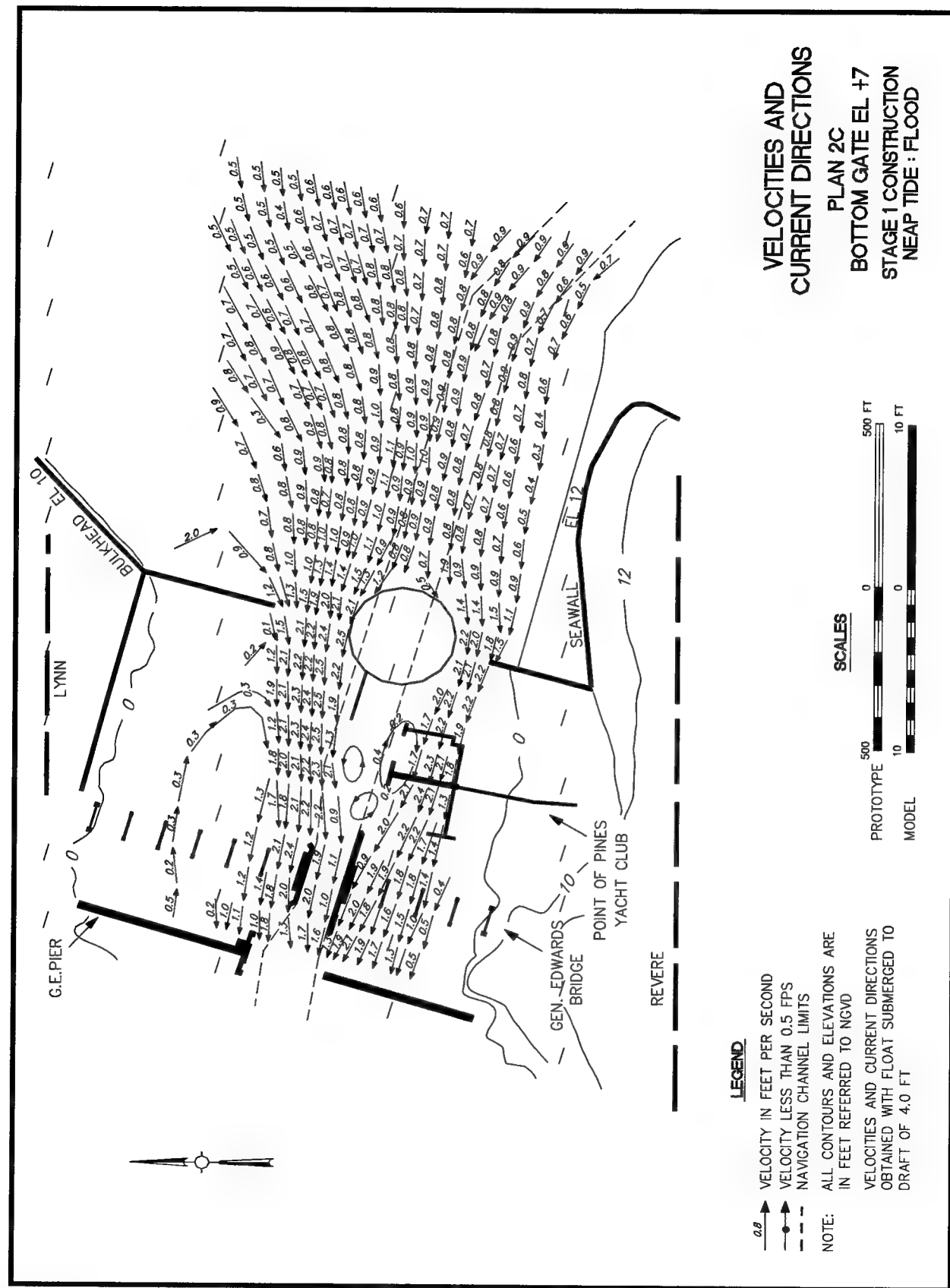
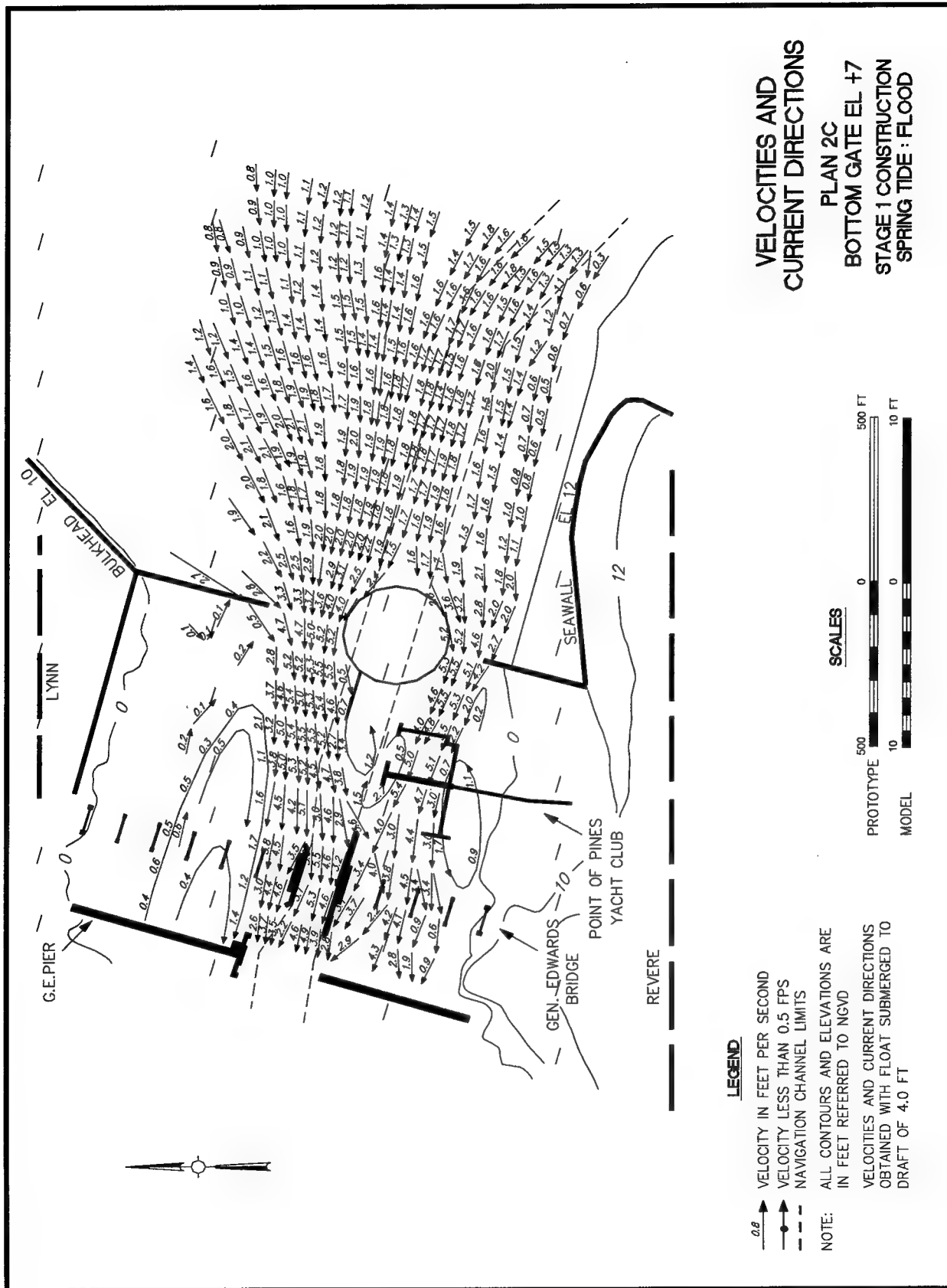
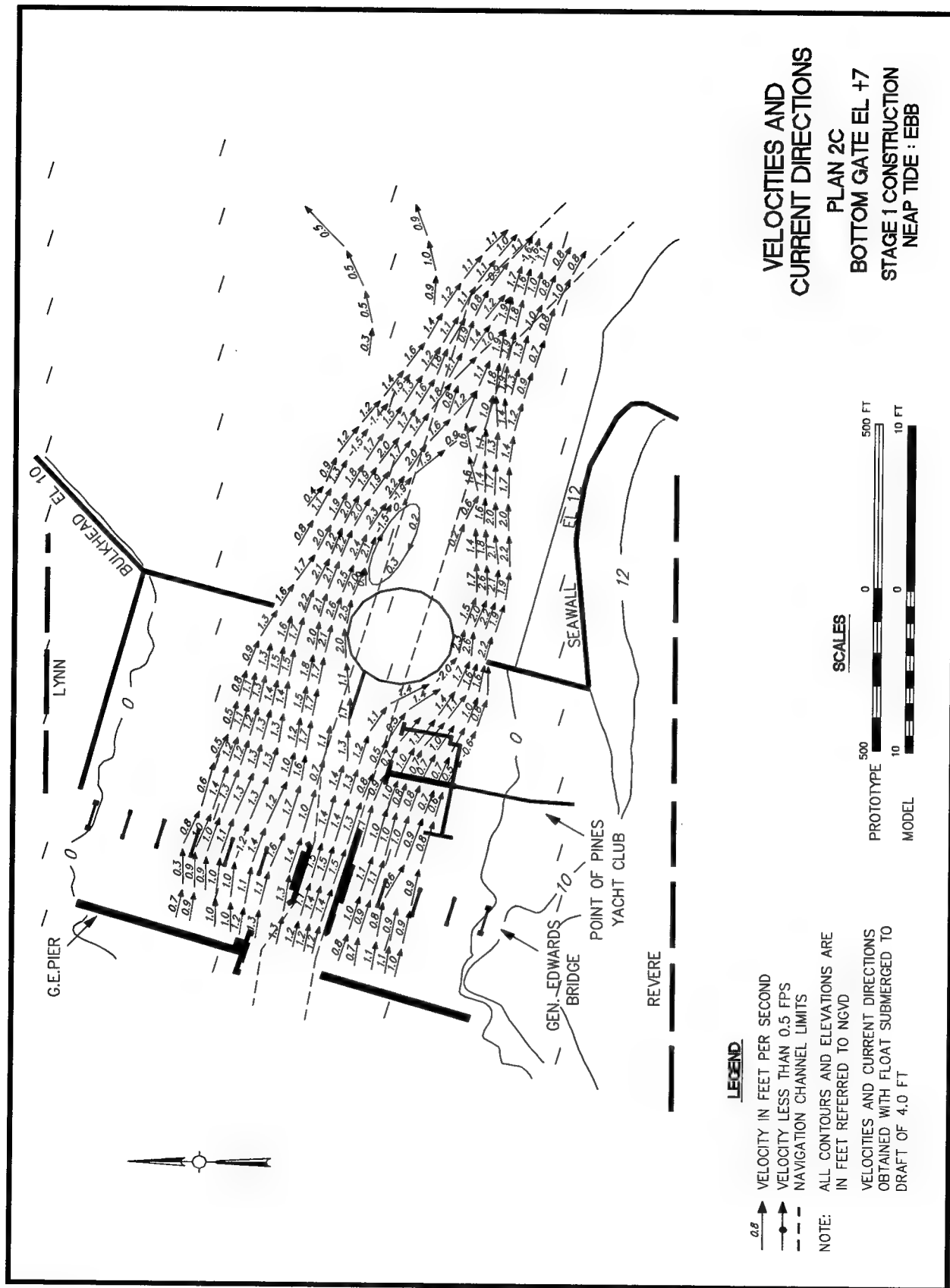


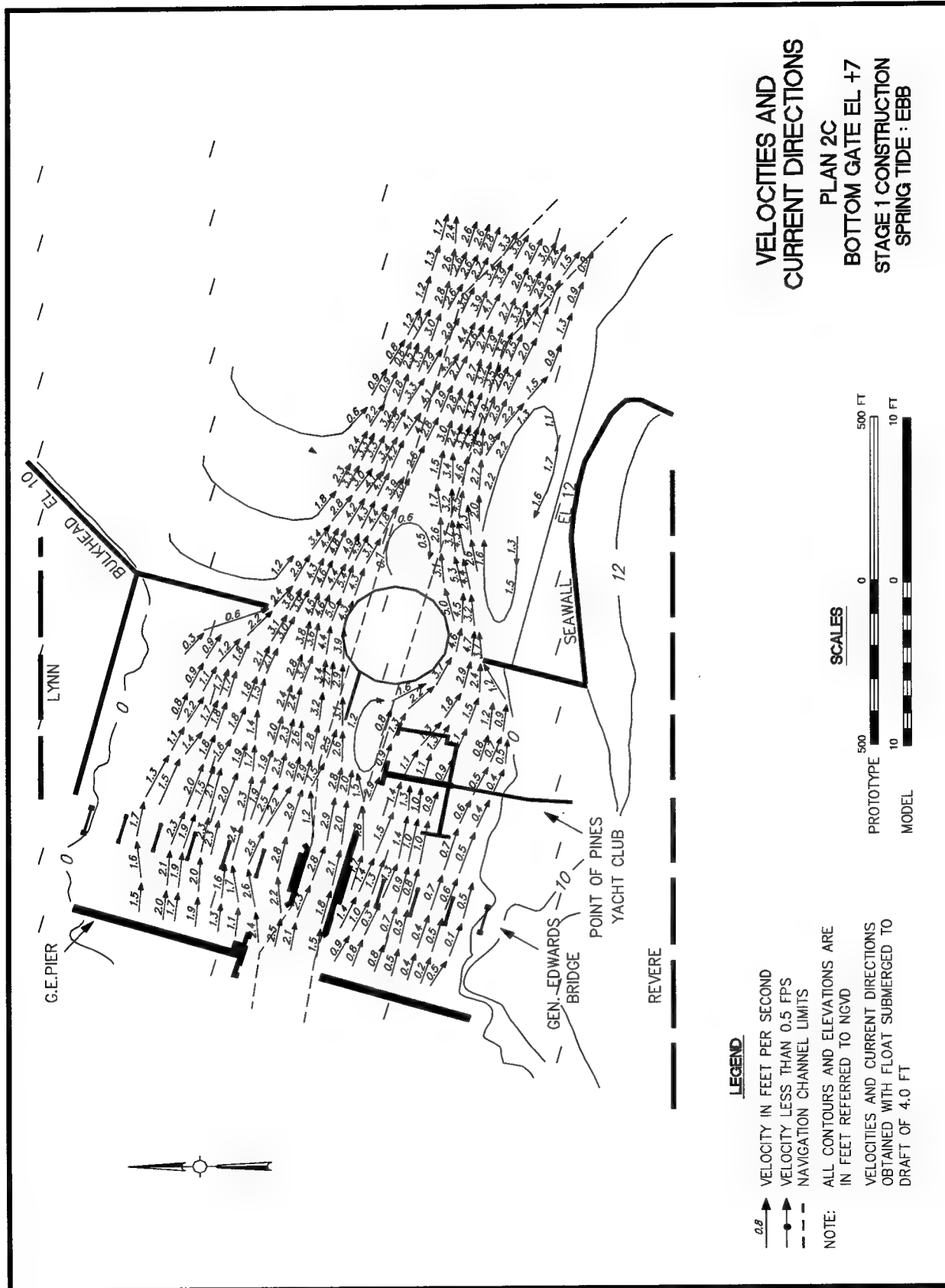
Plate 50

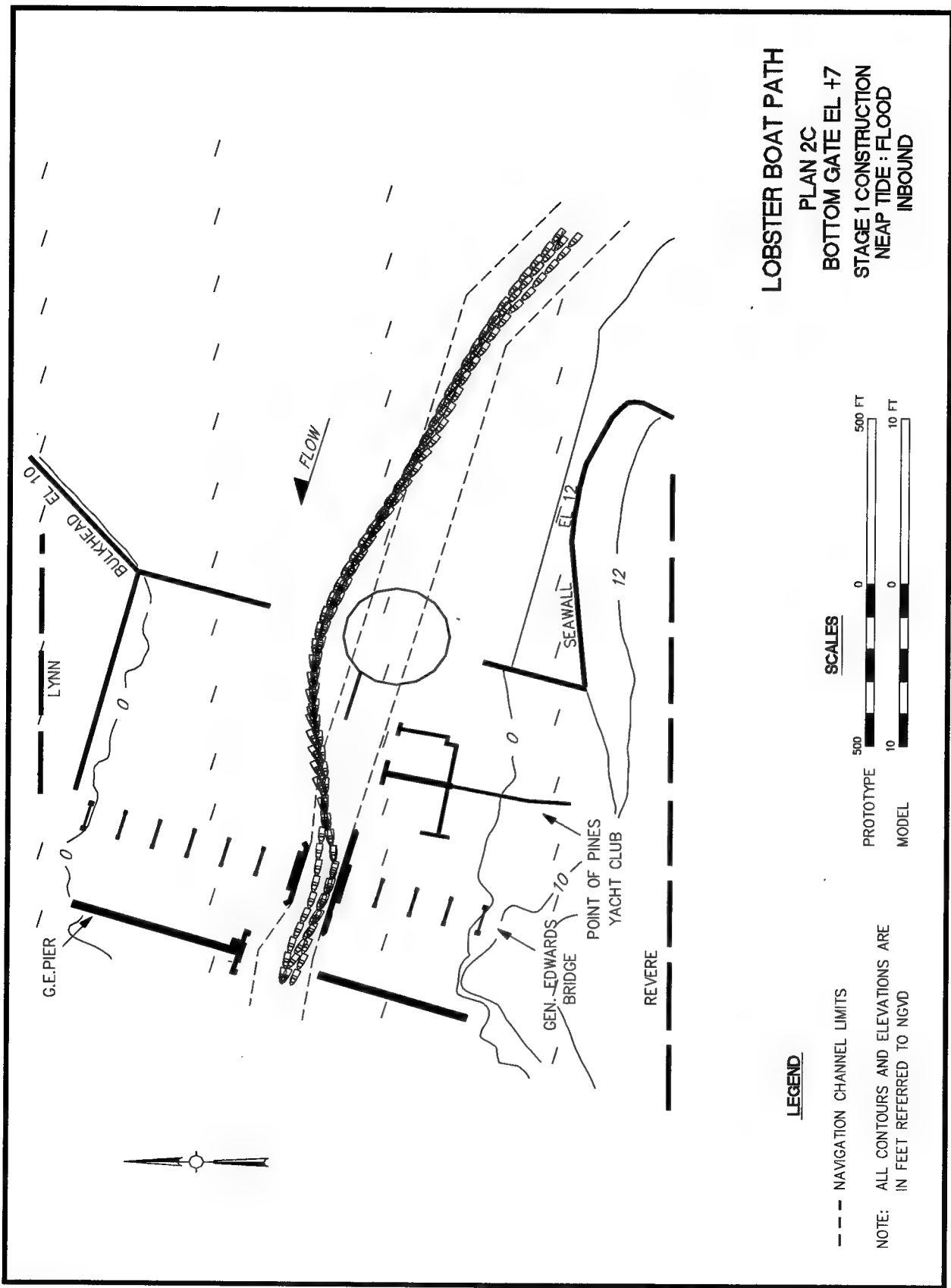


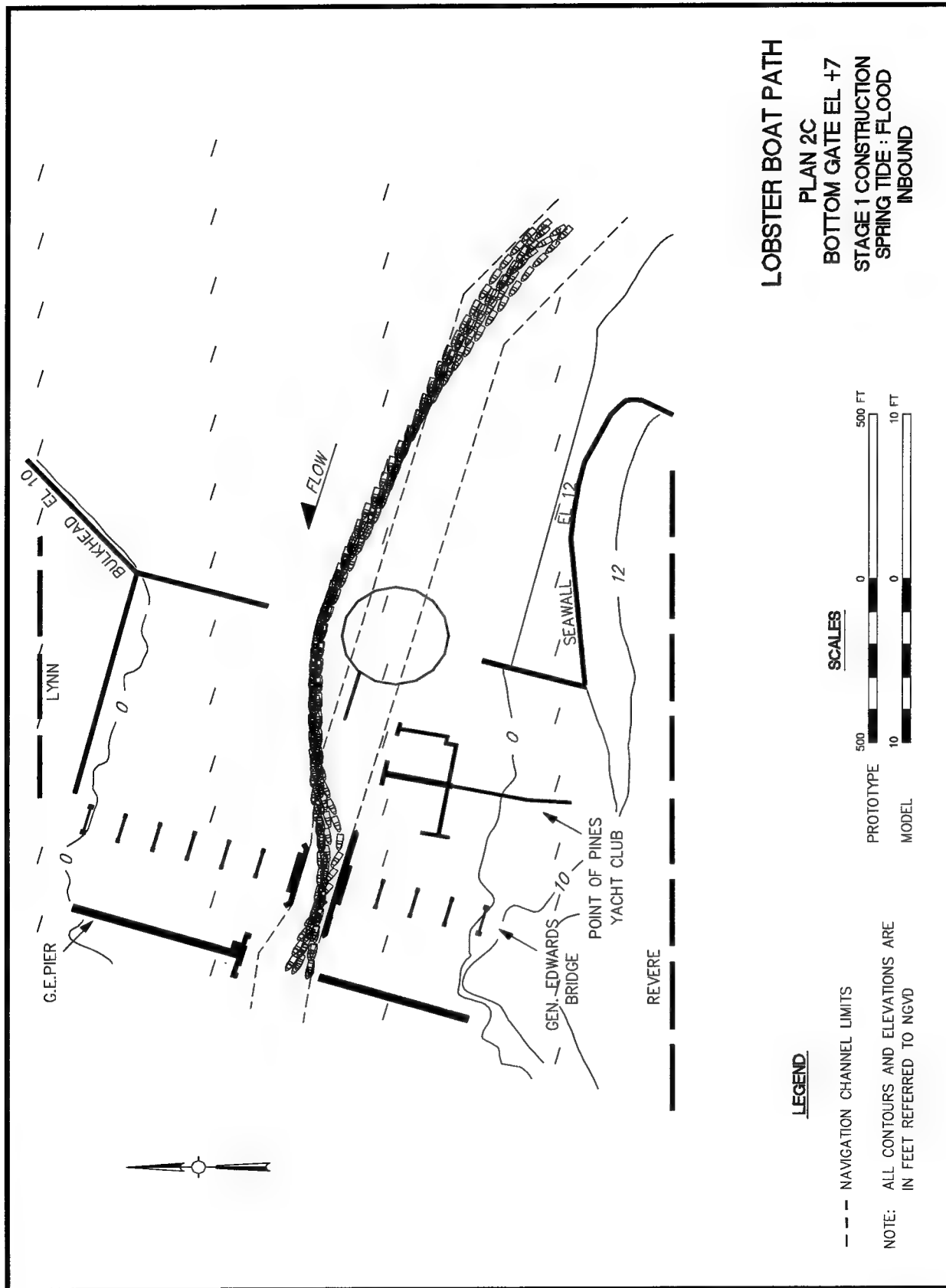












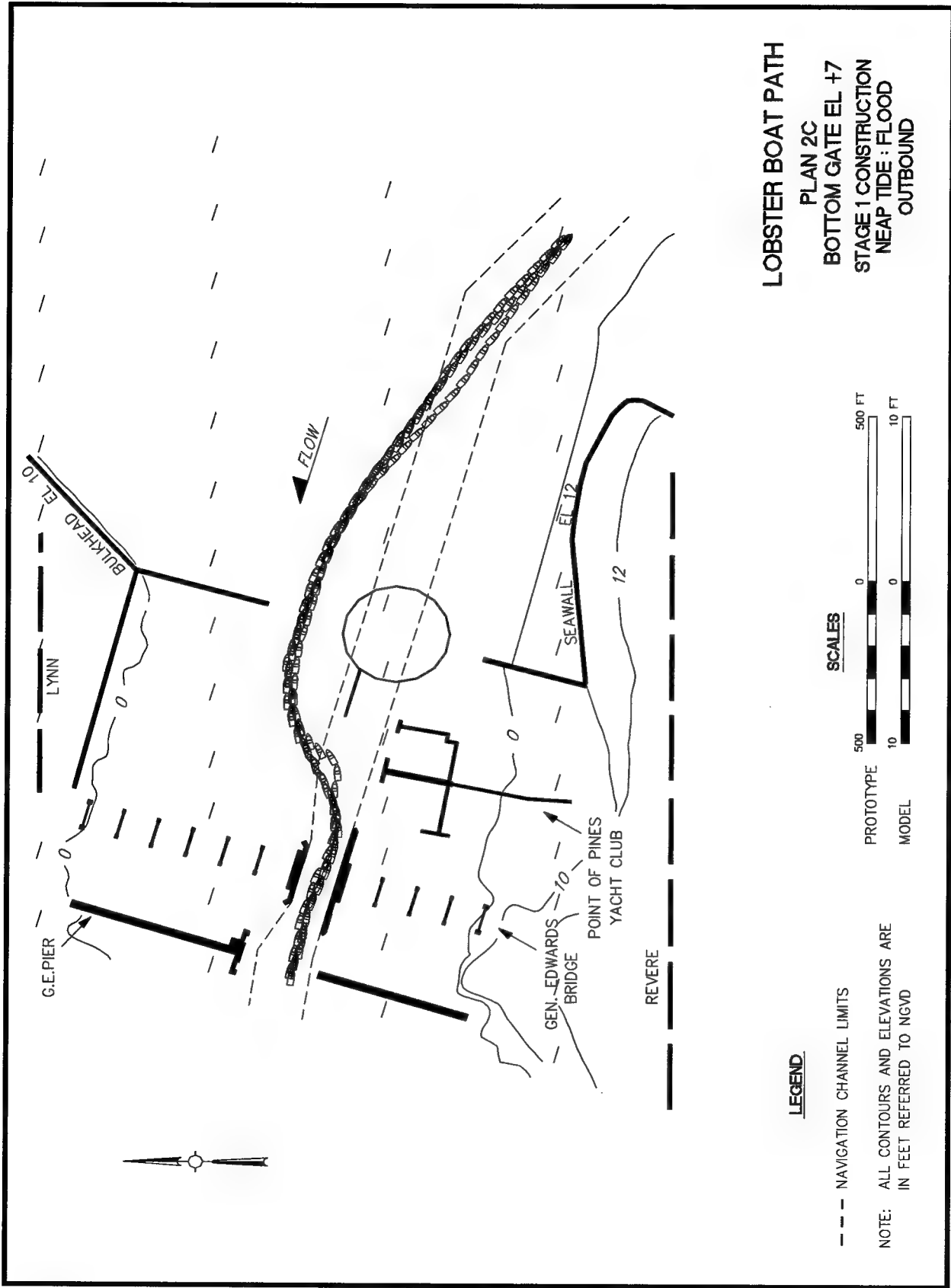
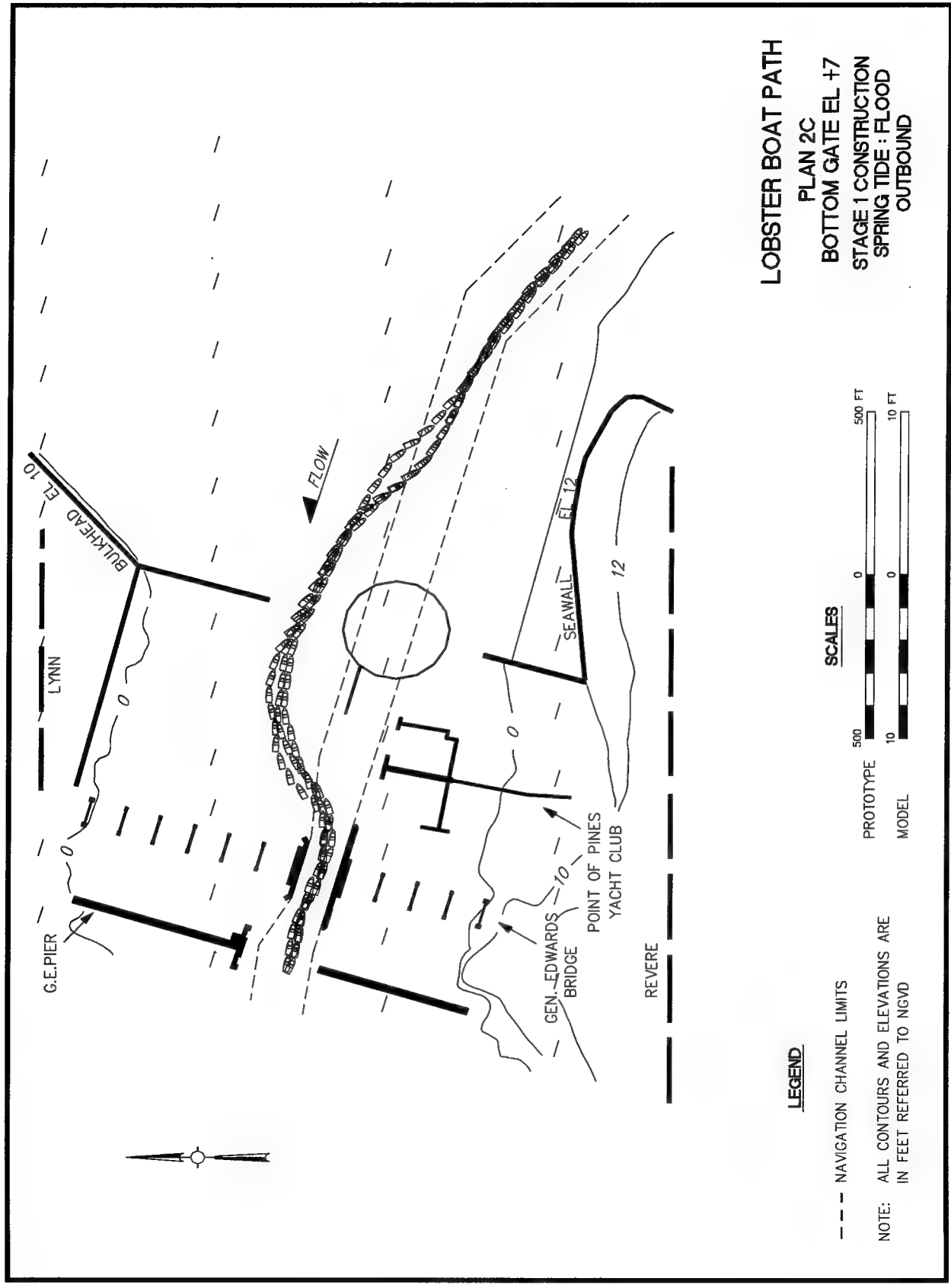


Plate 58



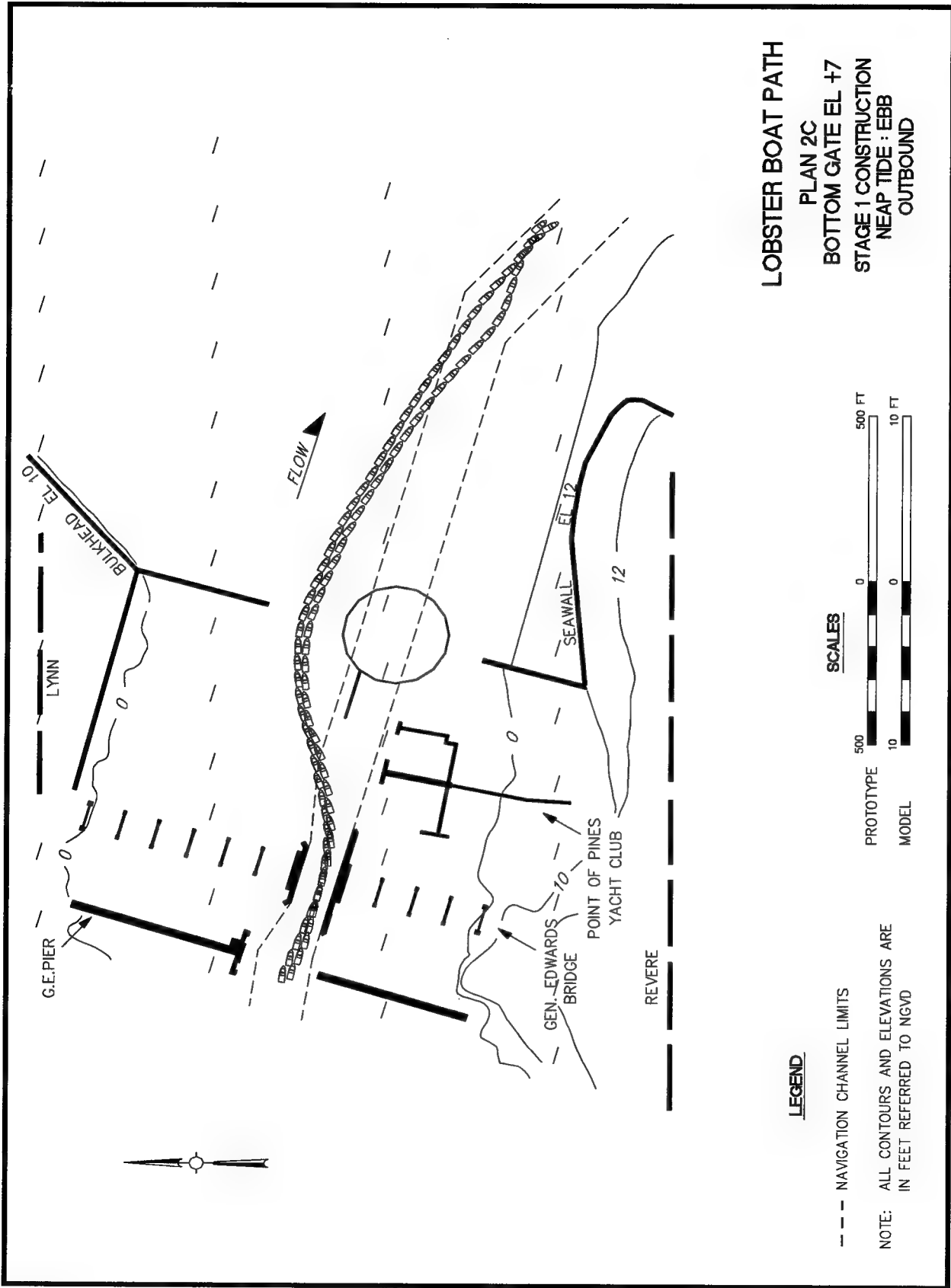
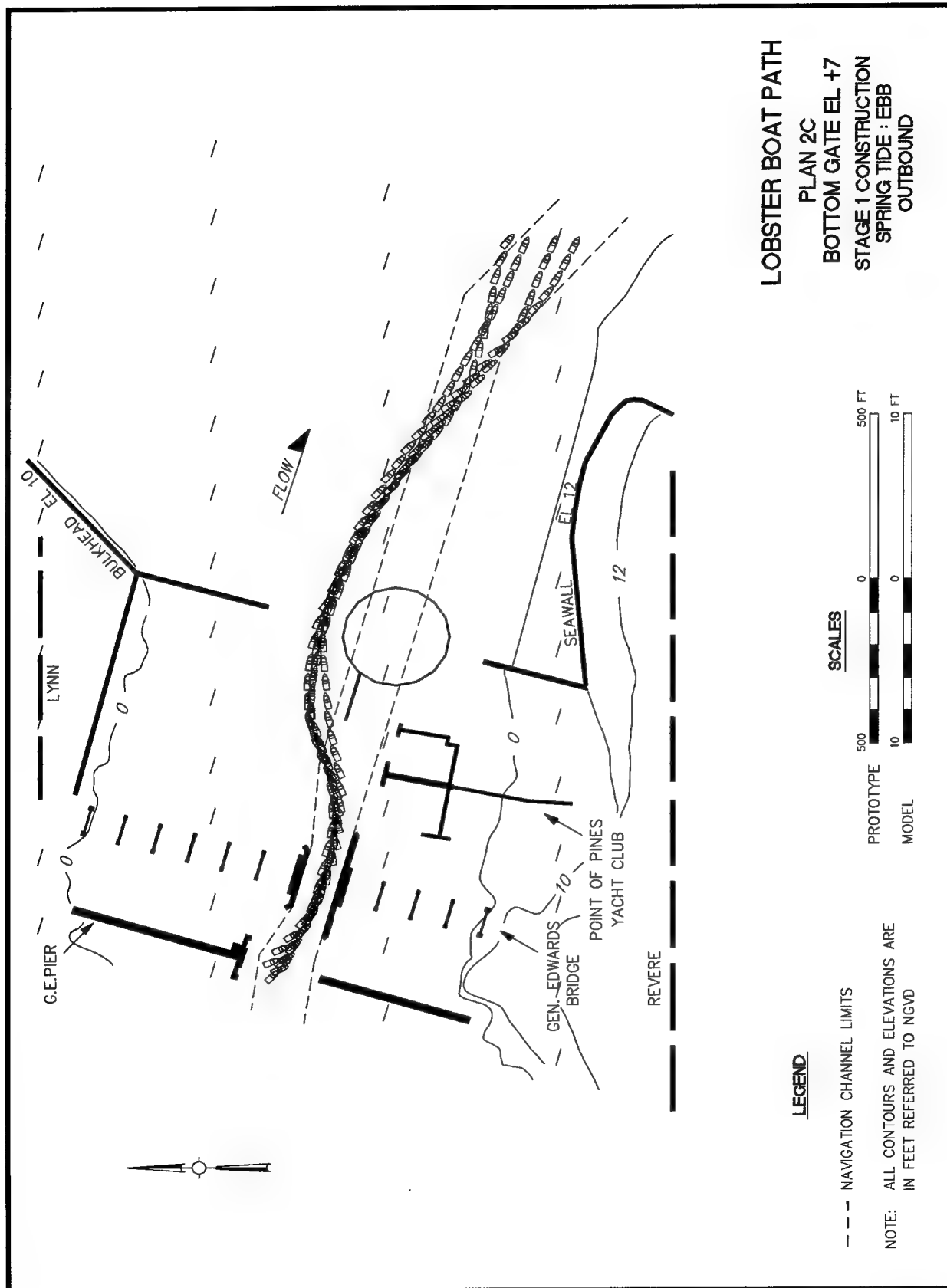


Plate 60



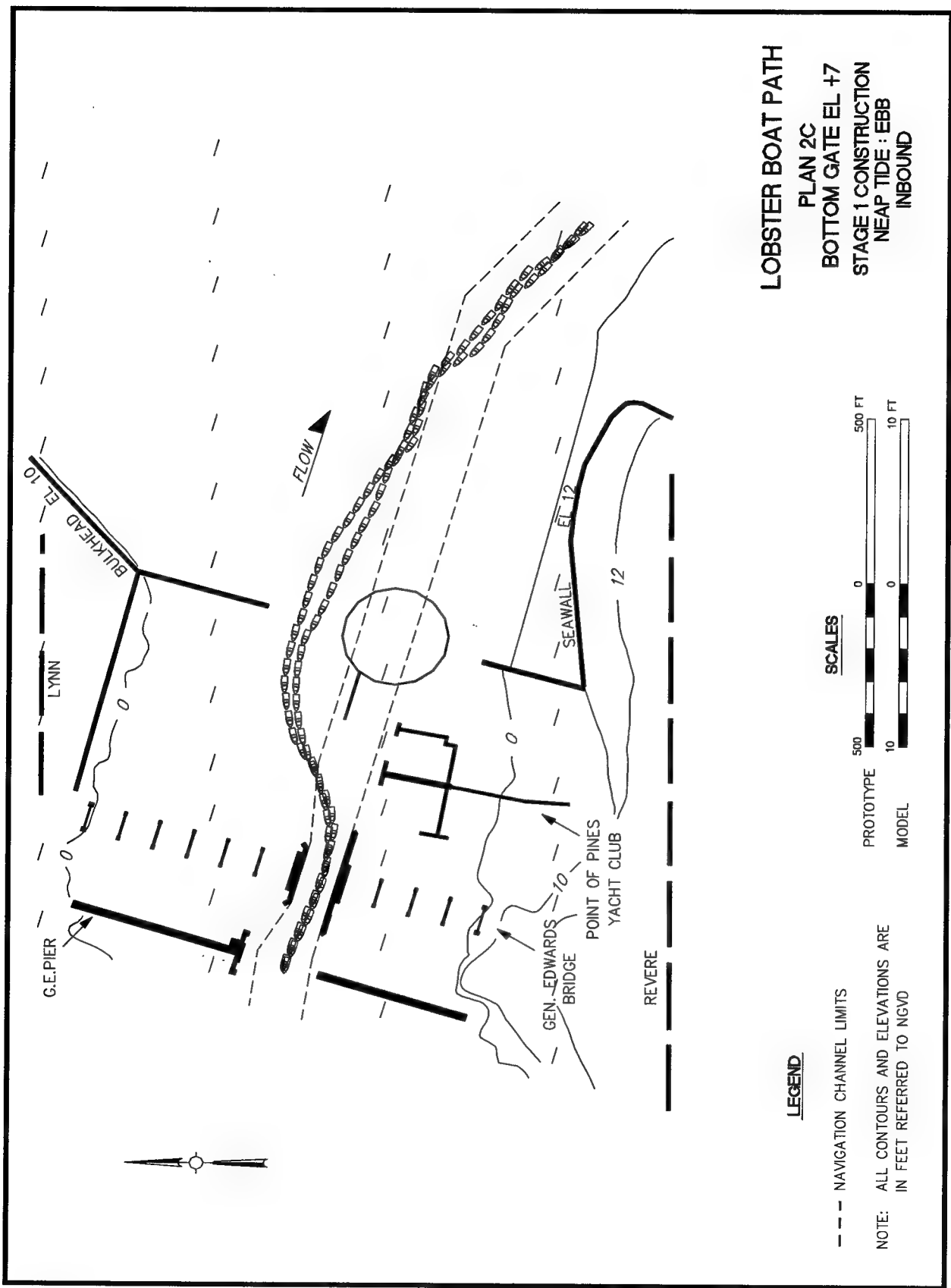
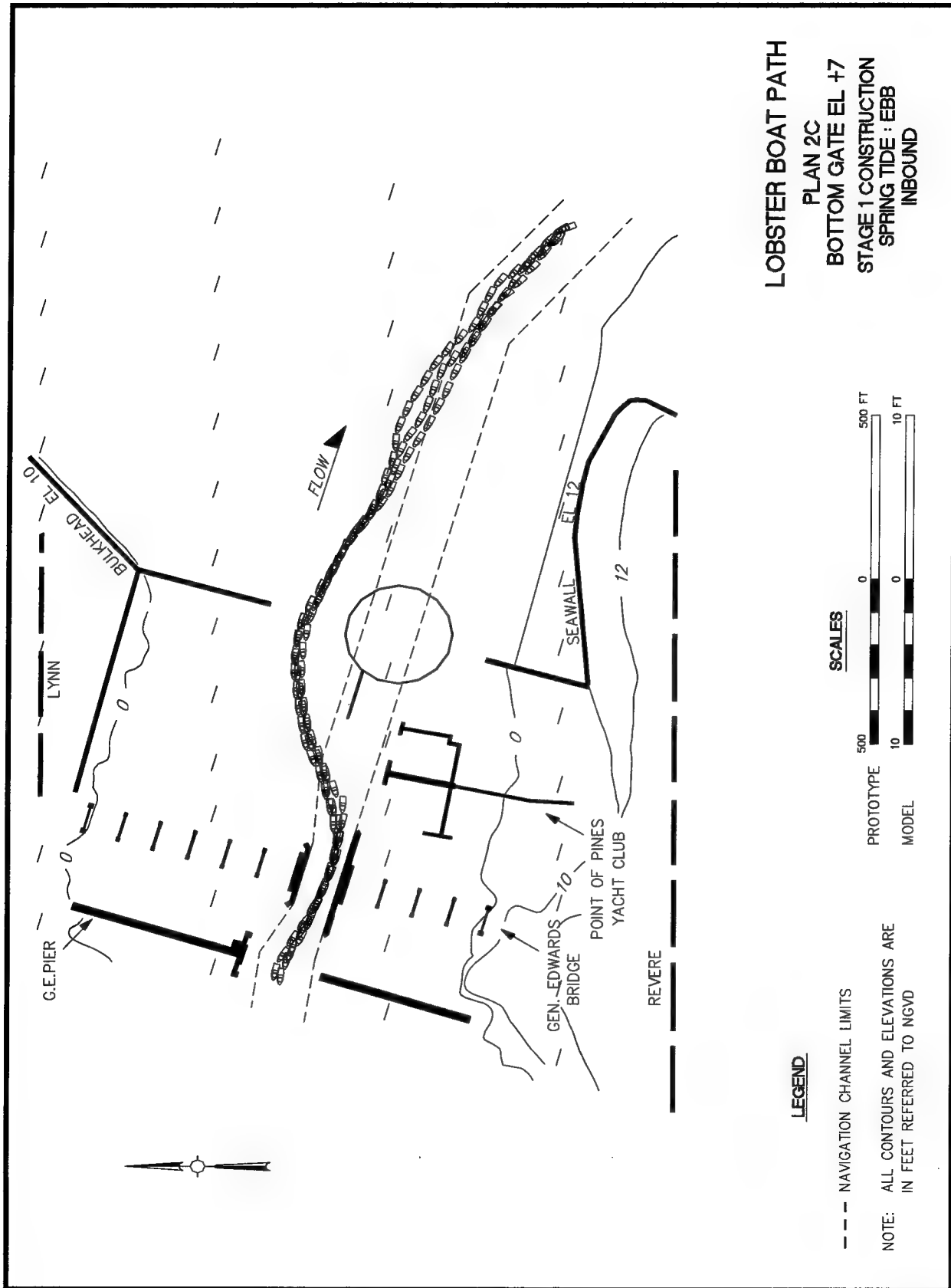
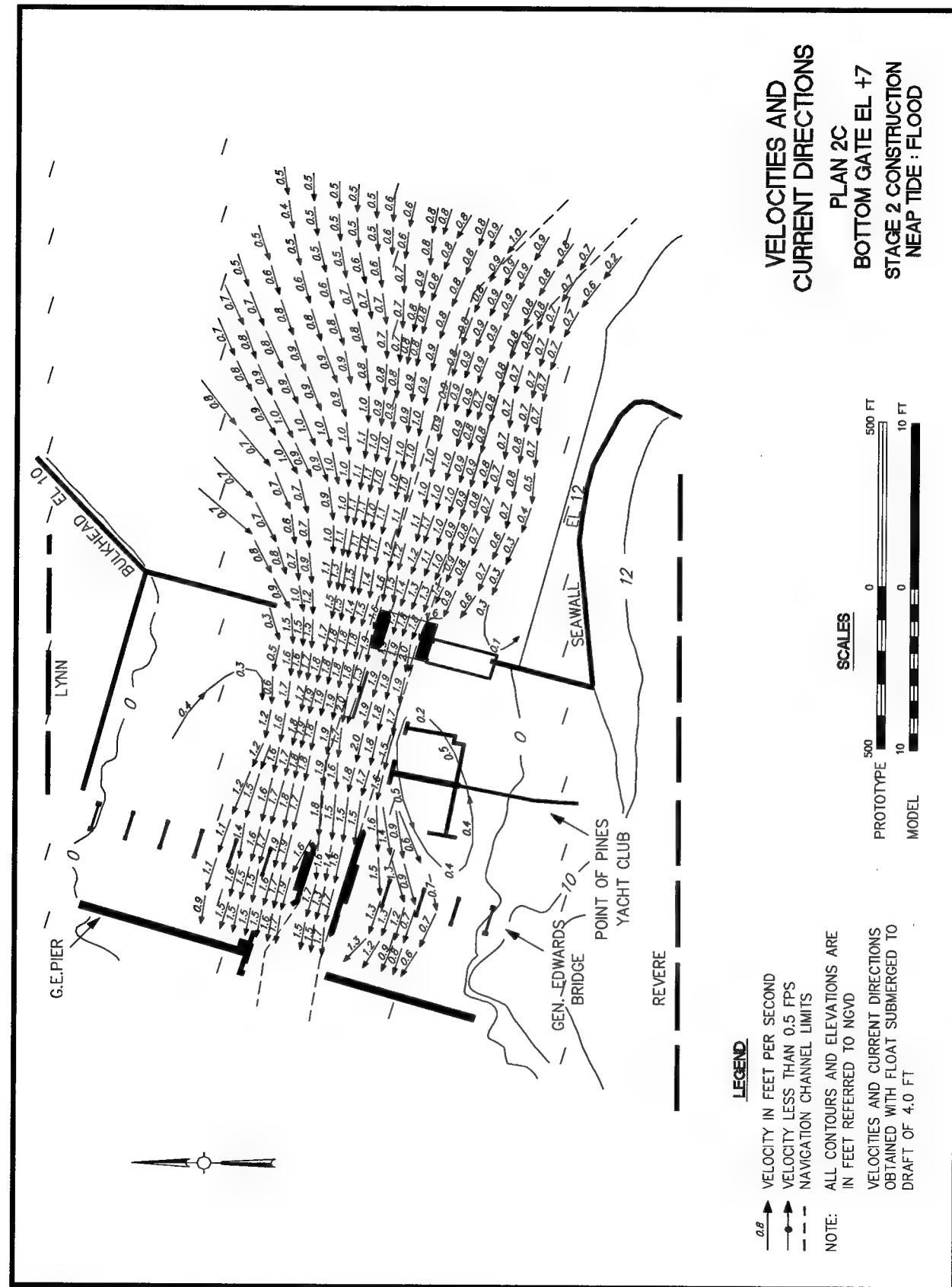
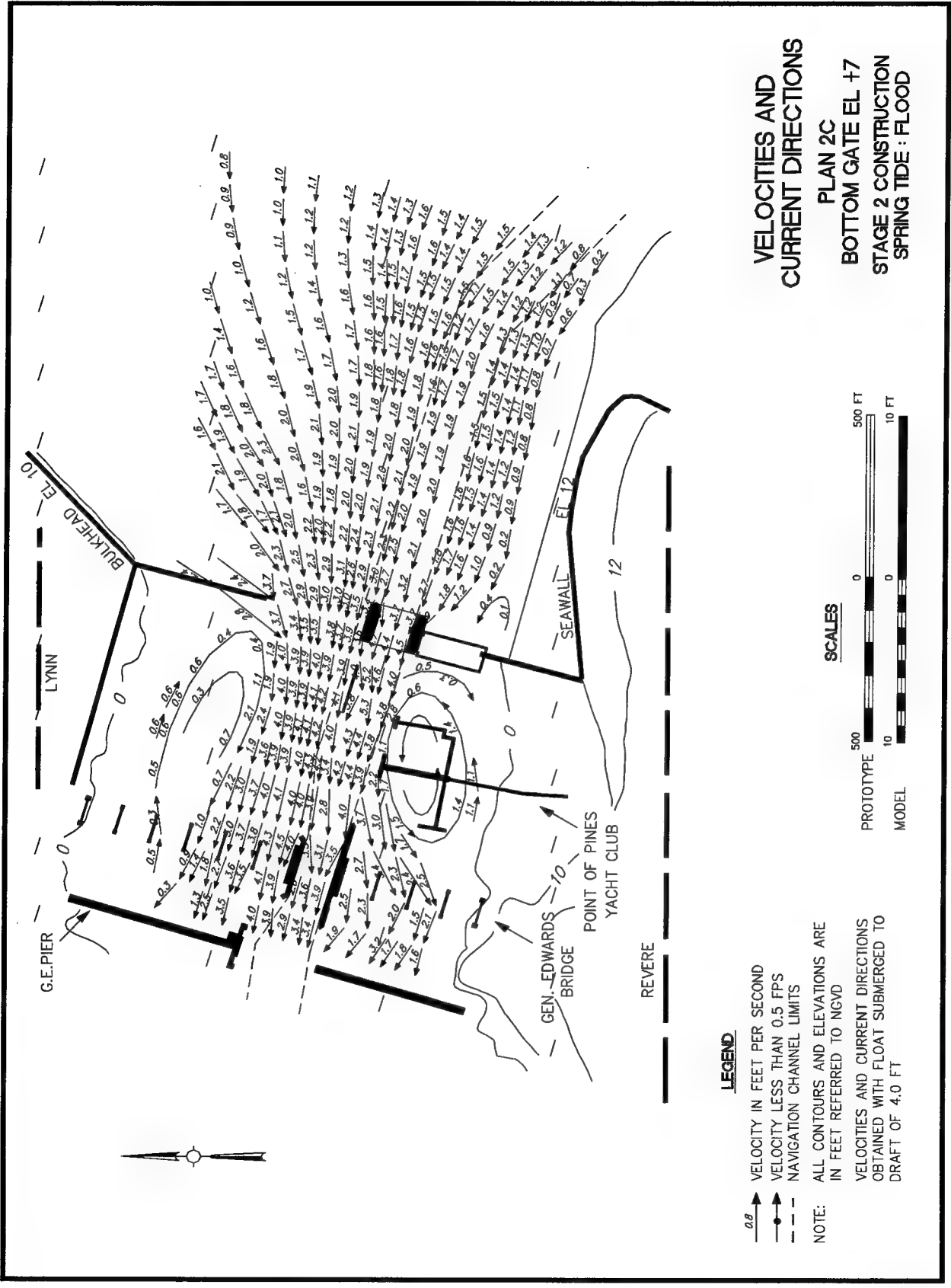
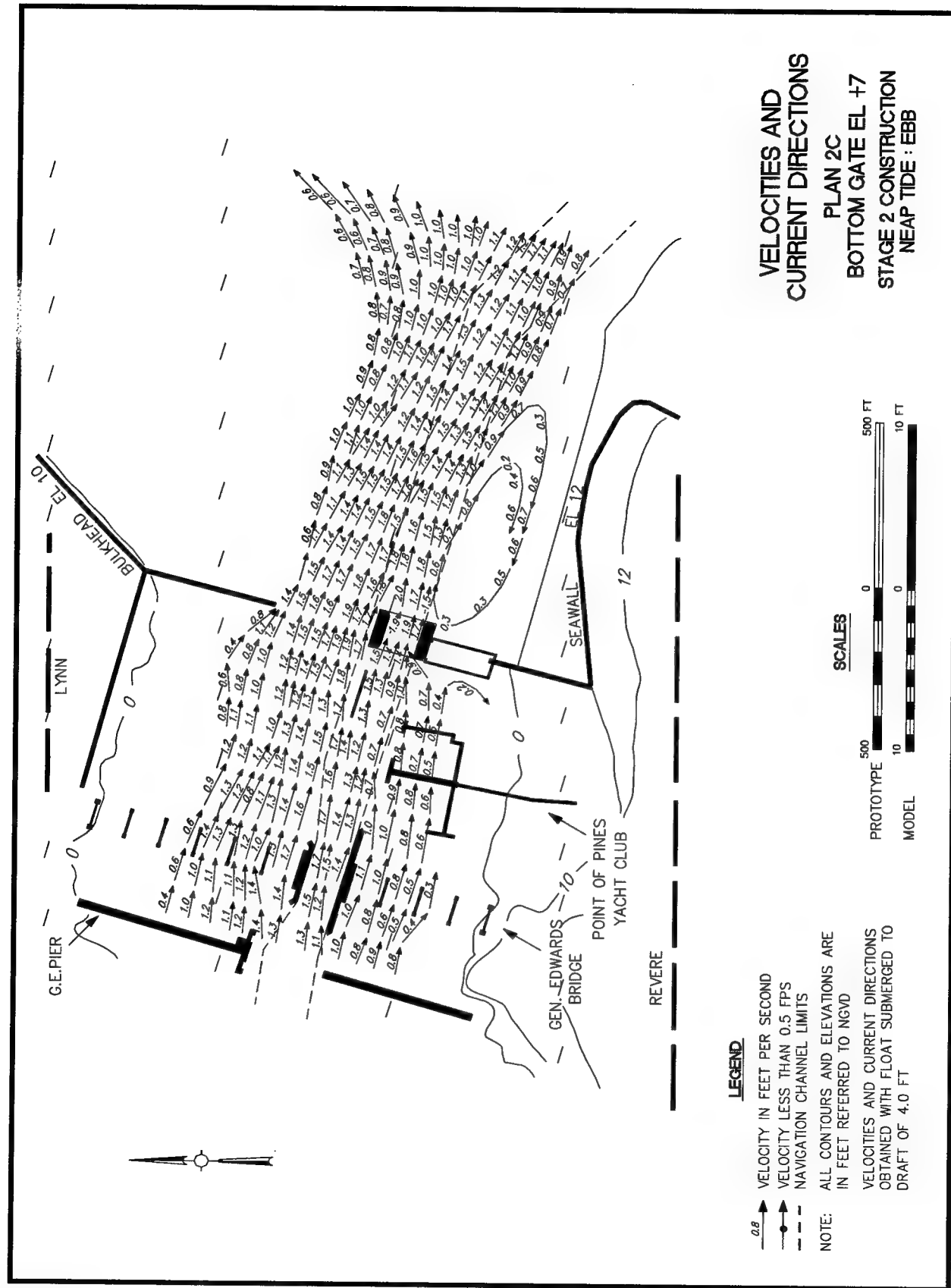


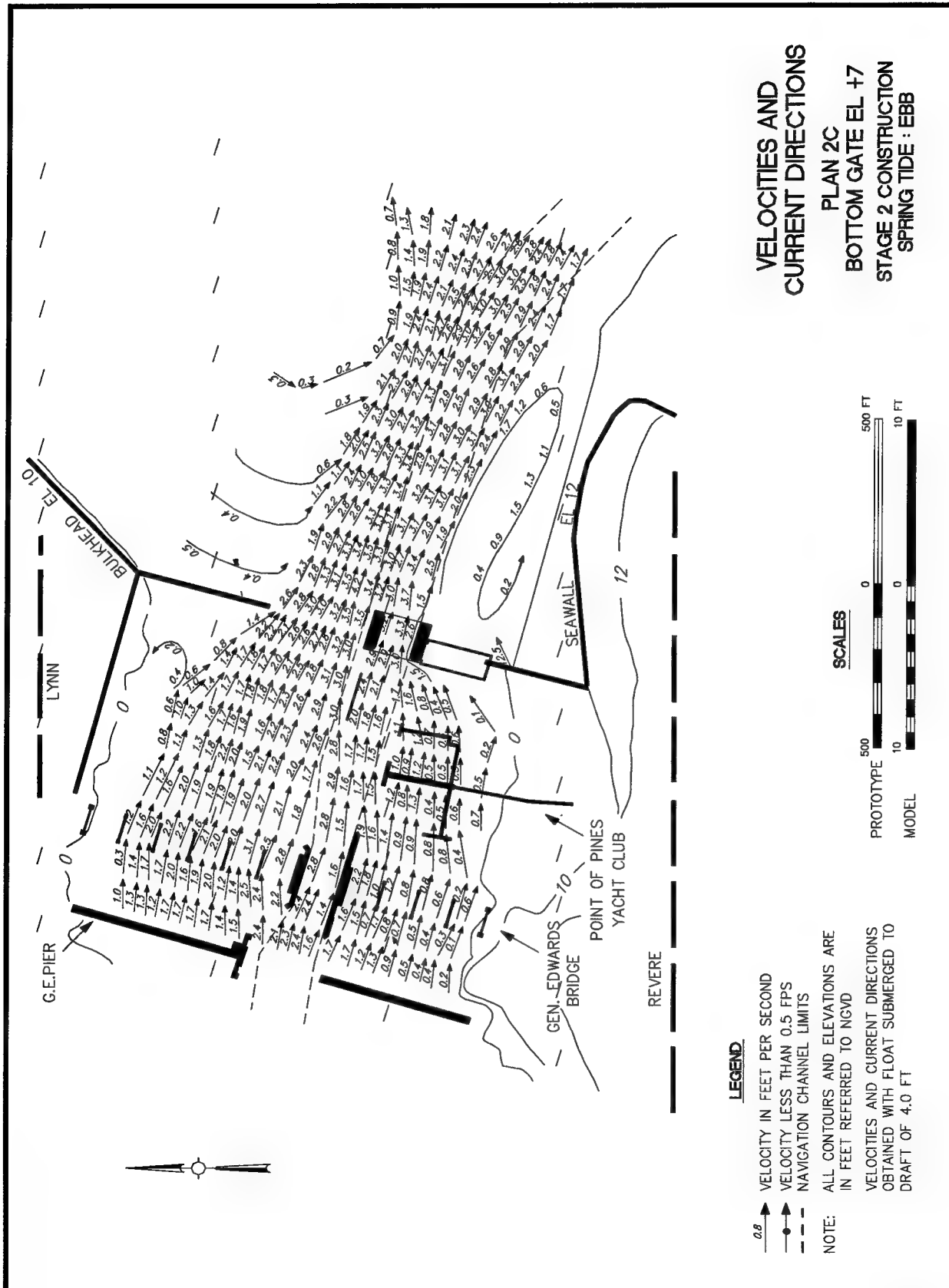
Plate 62

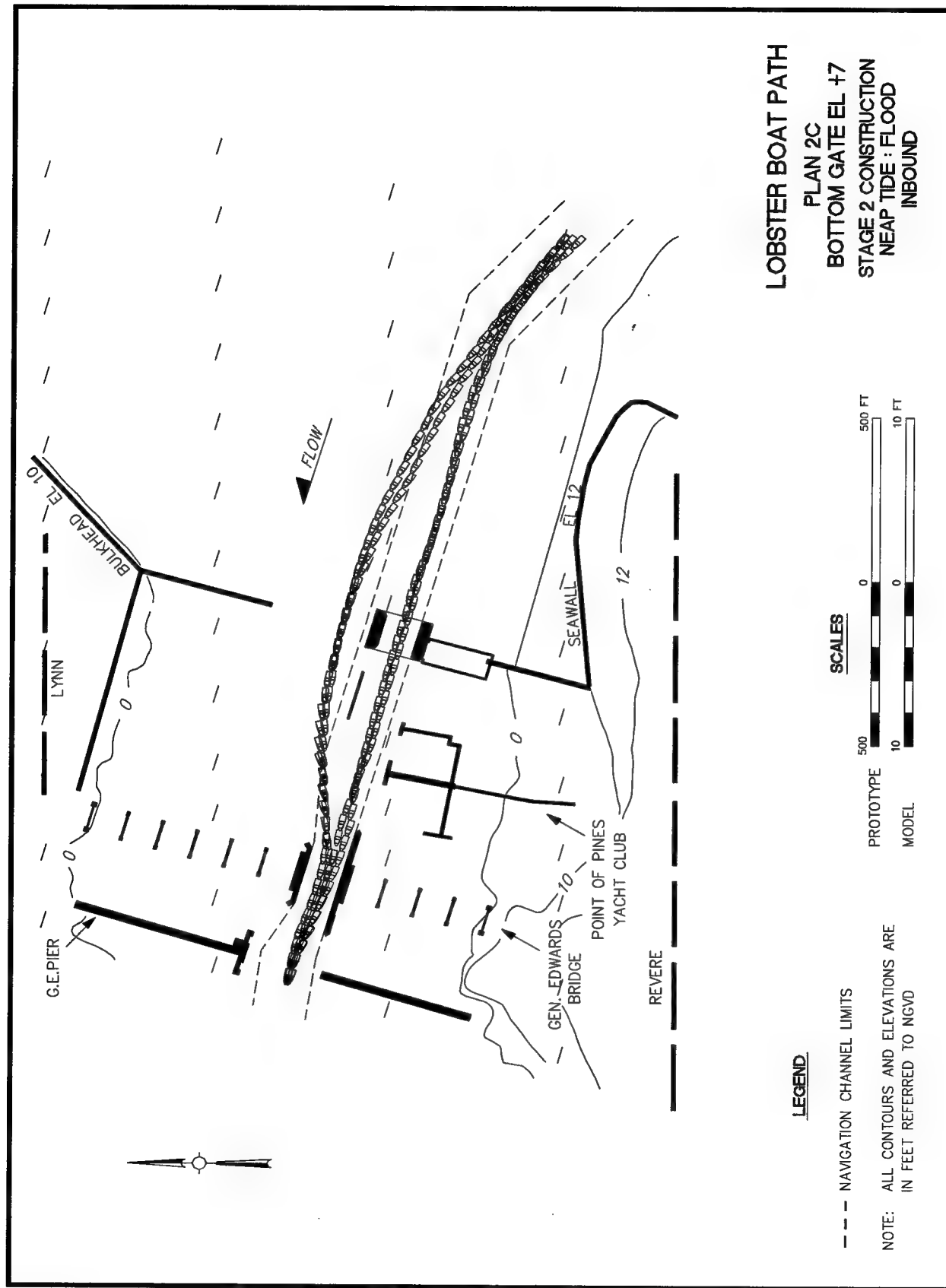


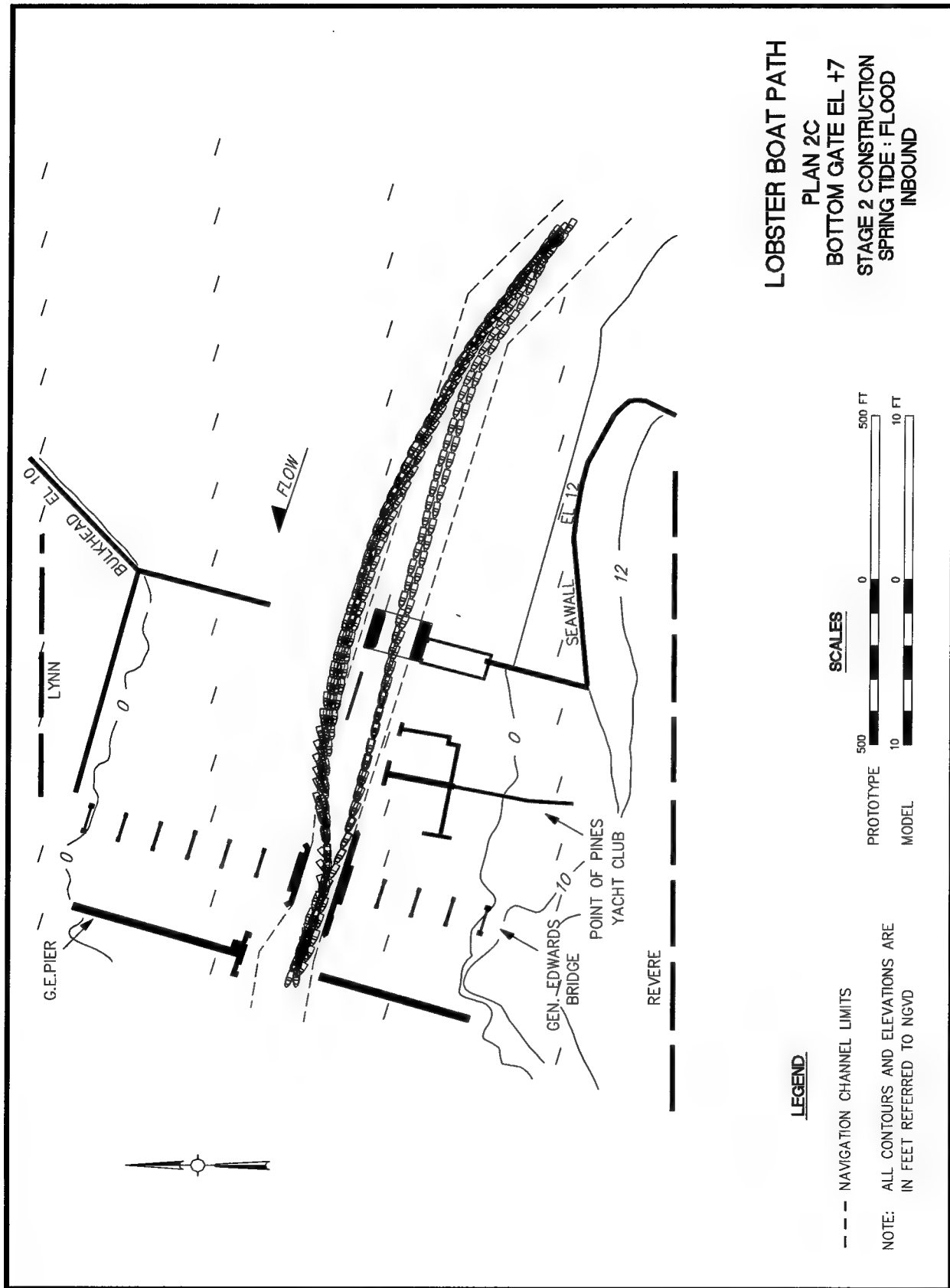












LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL +7
 STAGE 2 CONSTRUCTION
 SPRING TIDE : FLOOD
 INBOUND

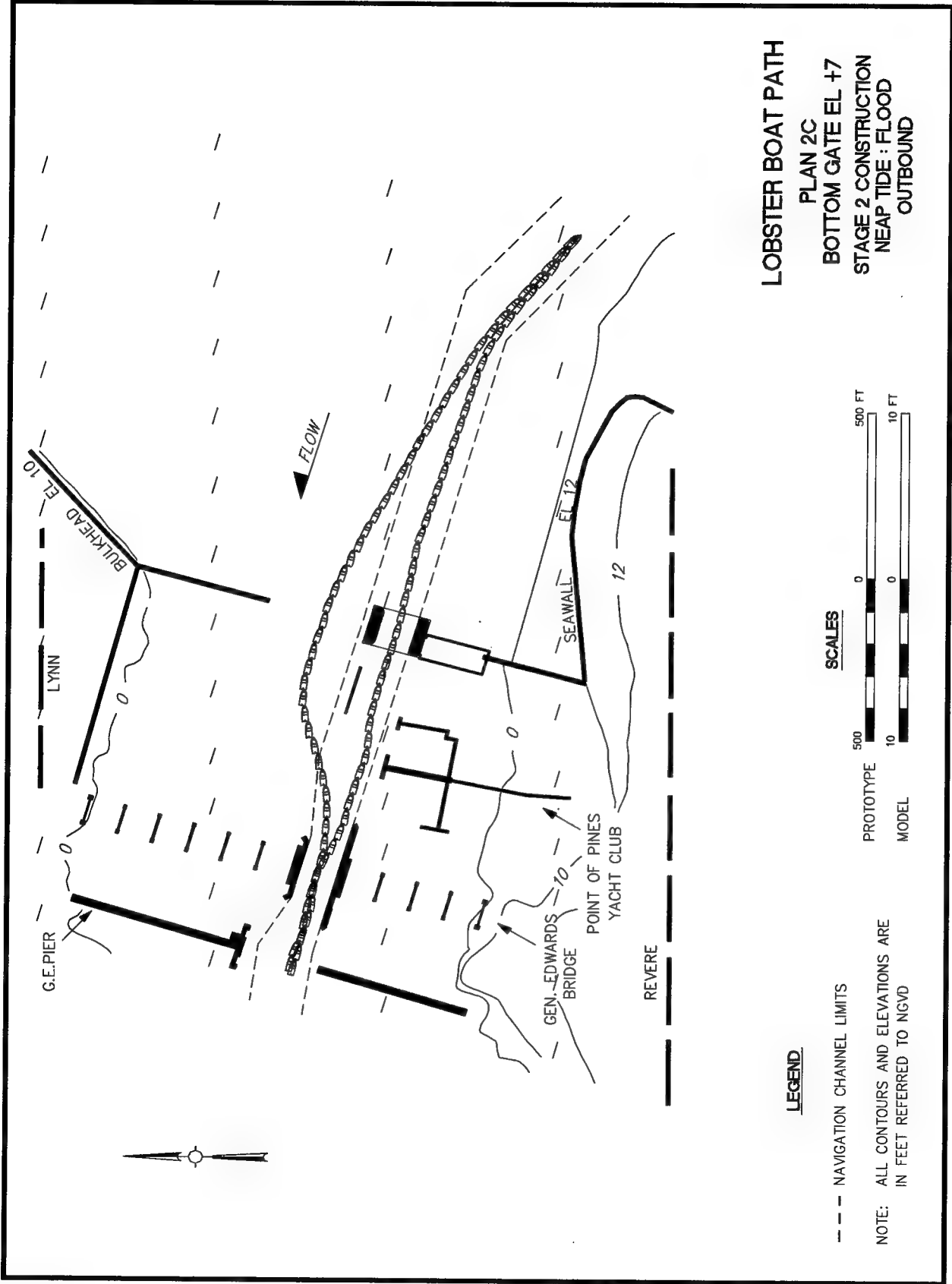
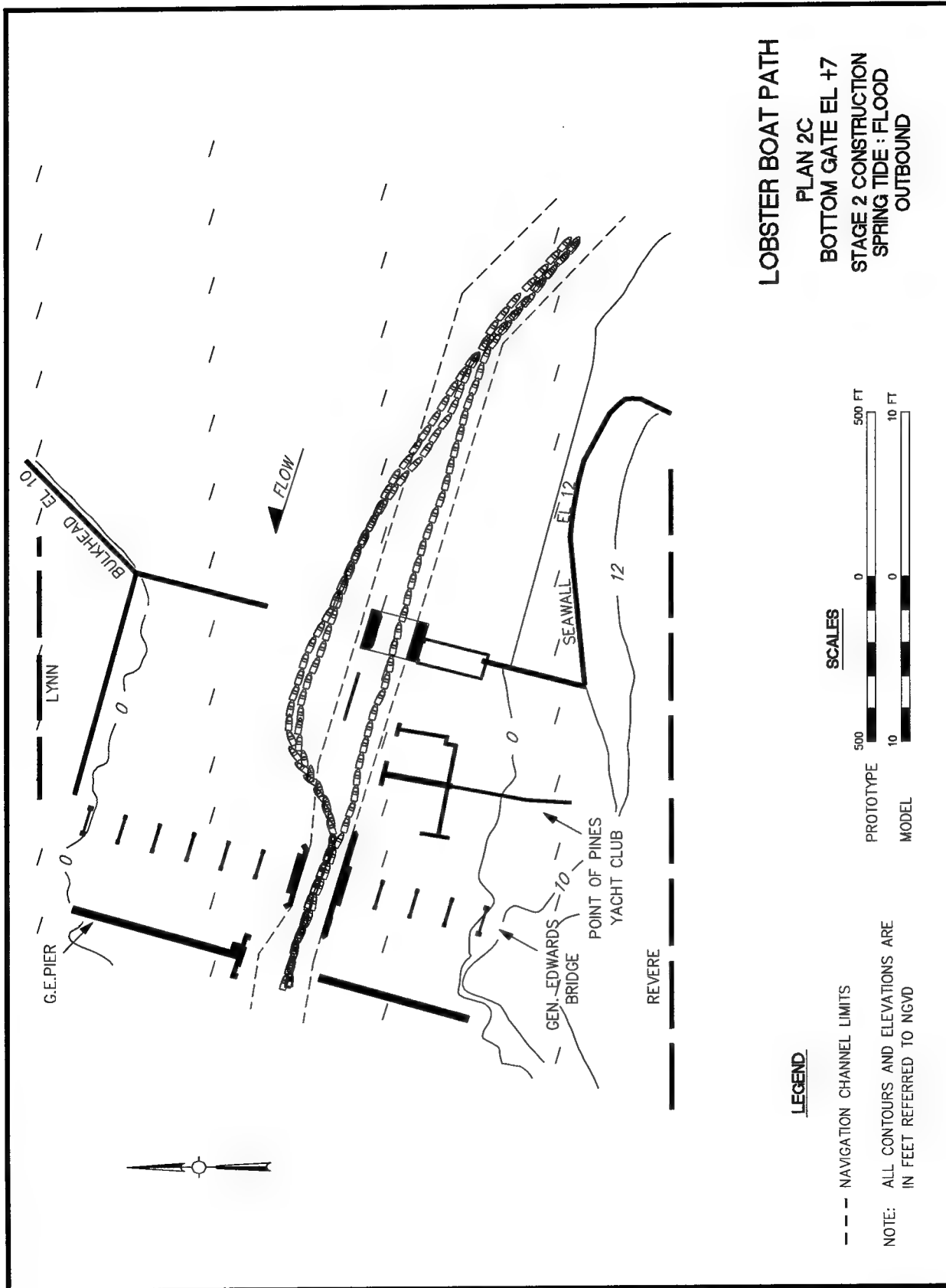


Plate 70



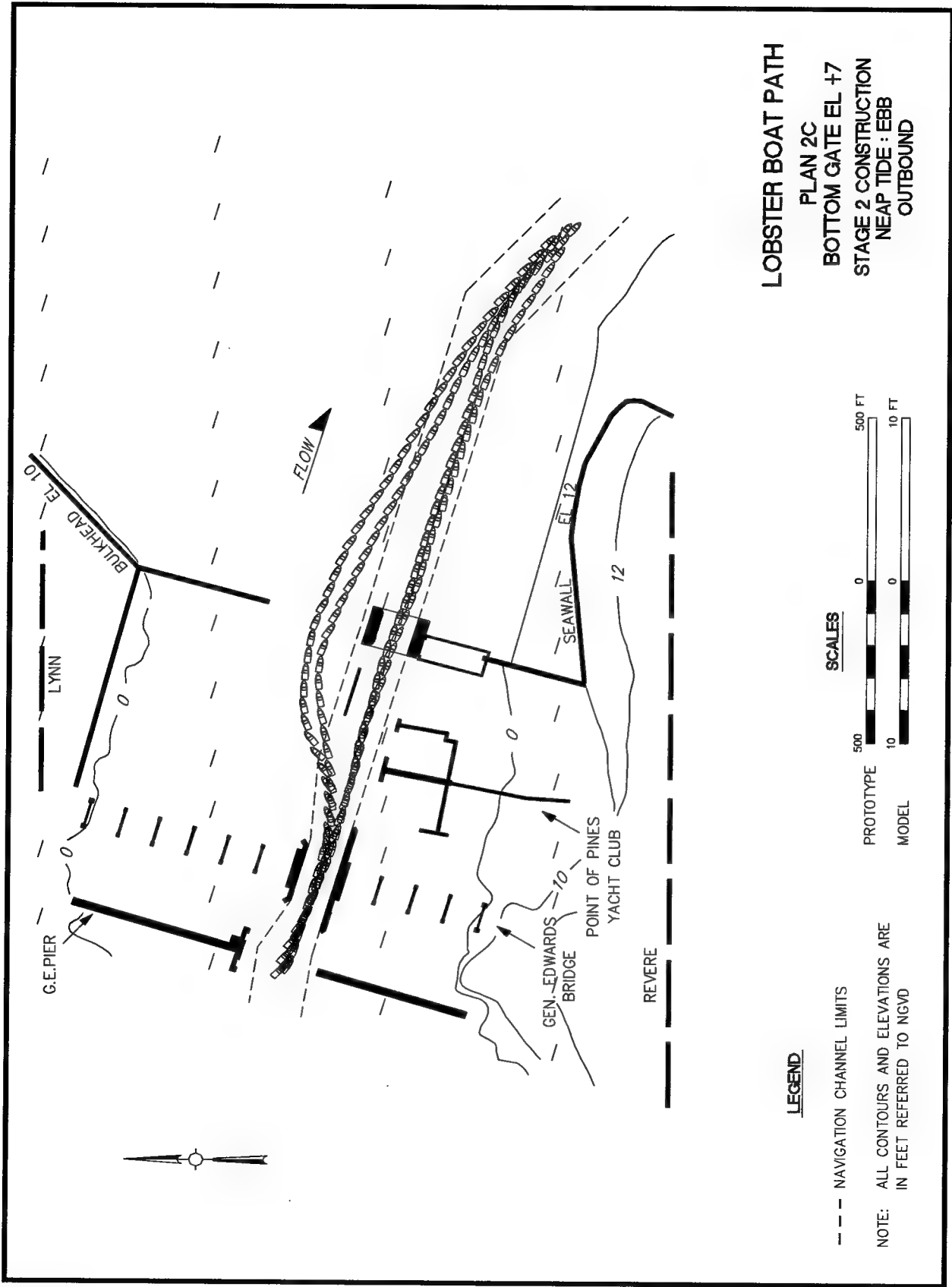
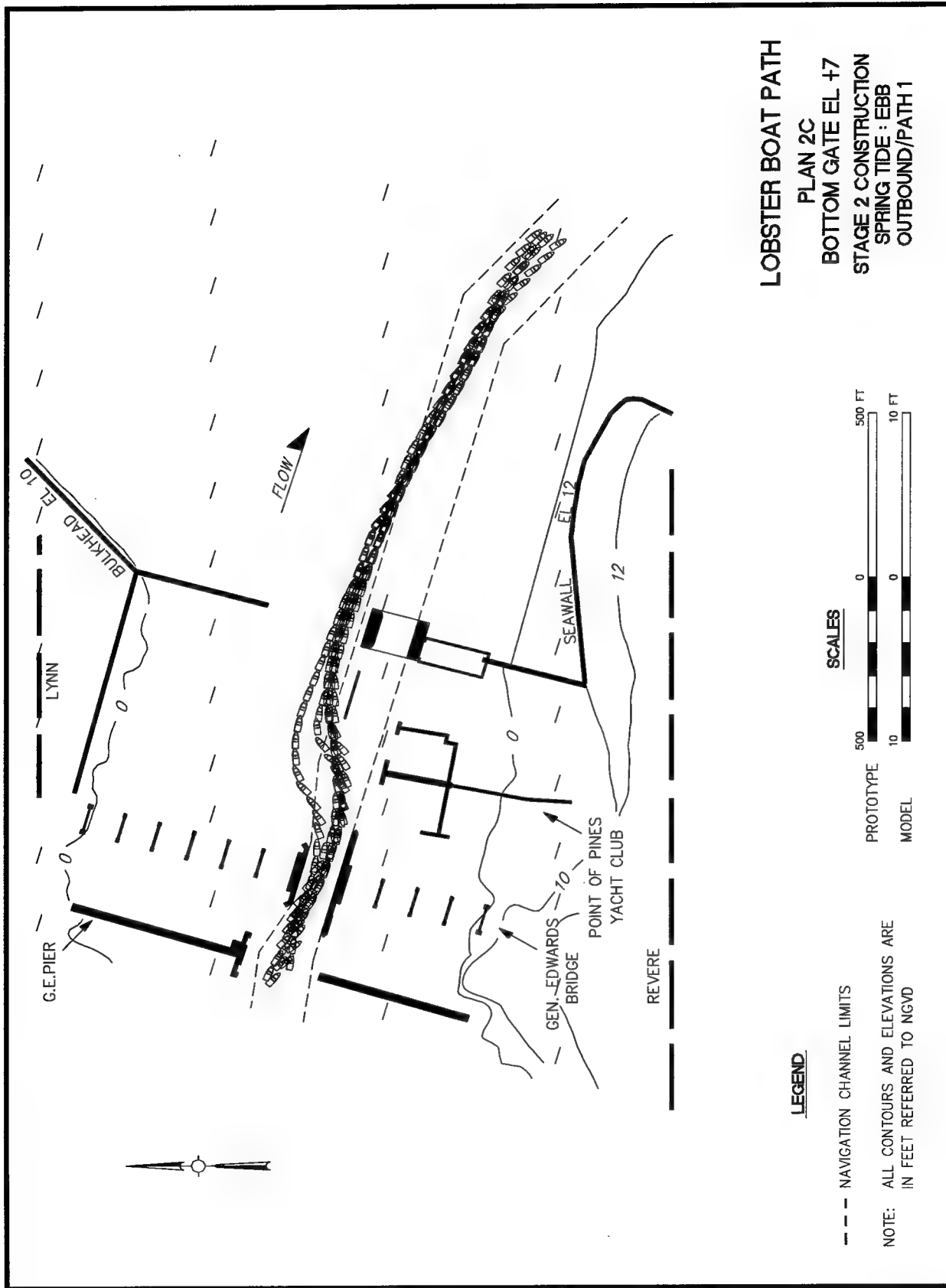


Plate 72



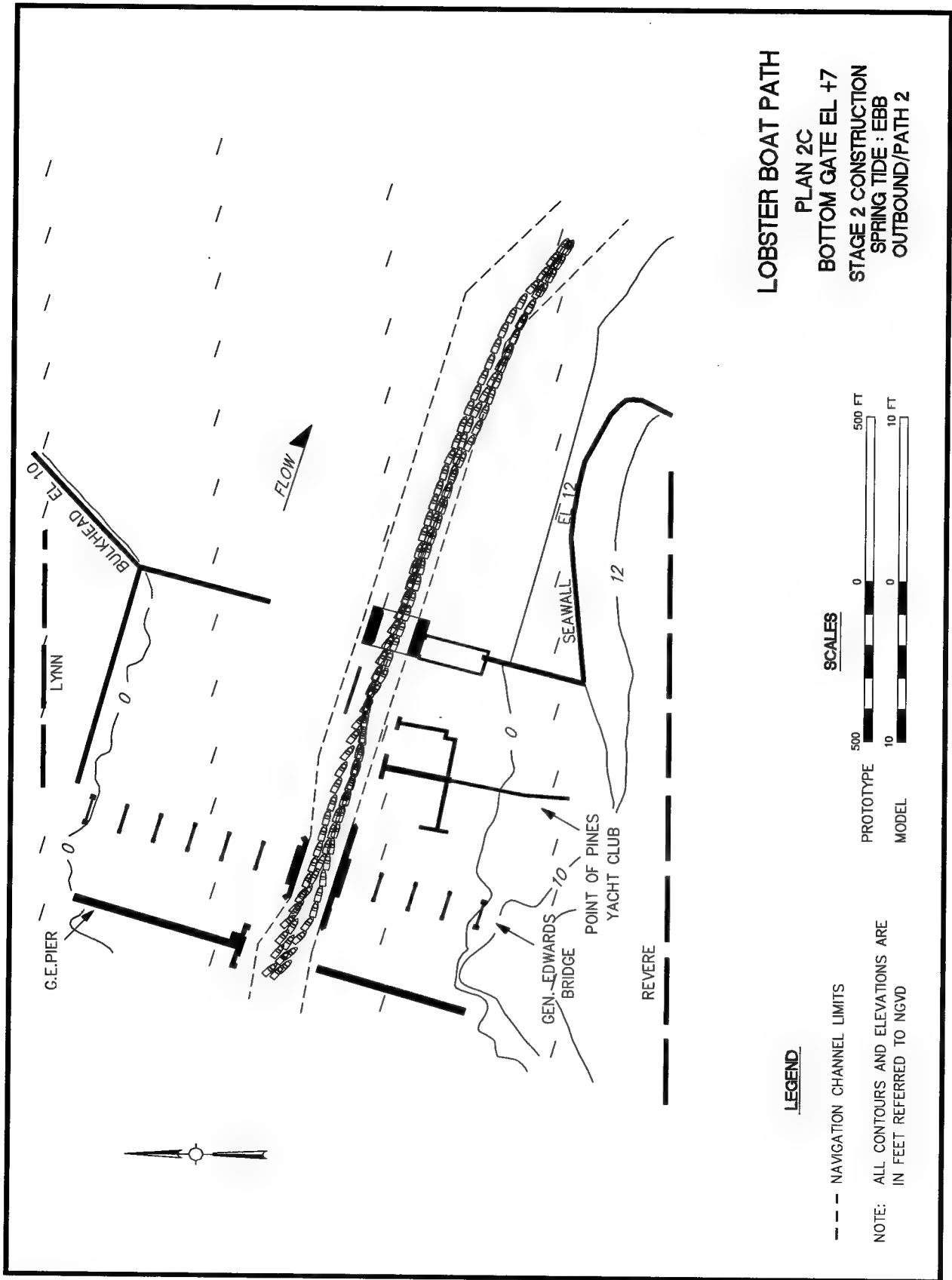
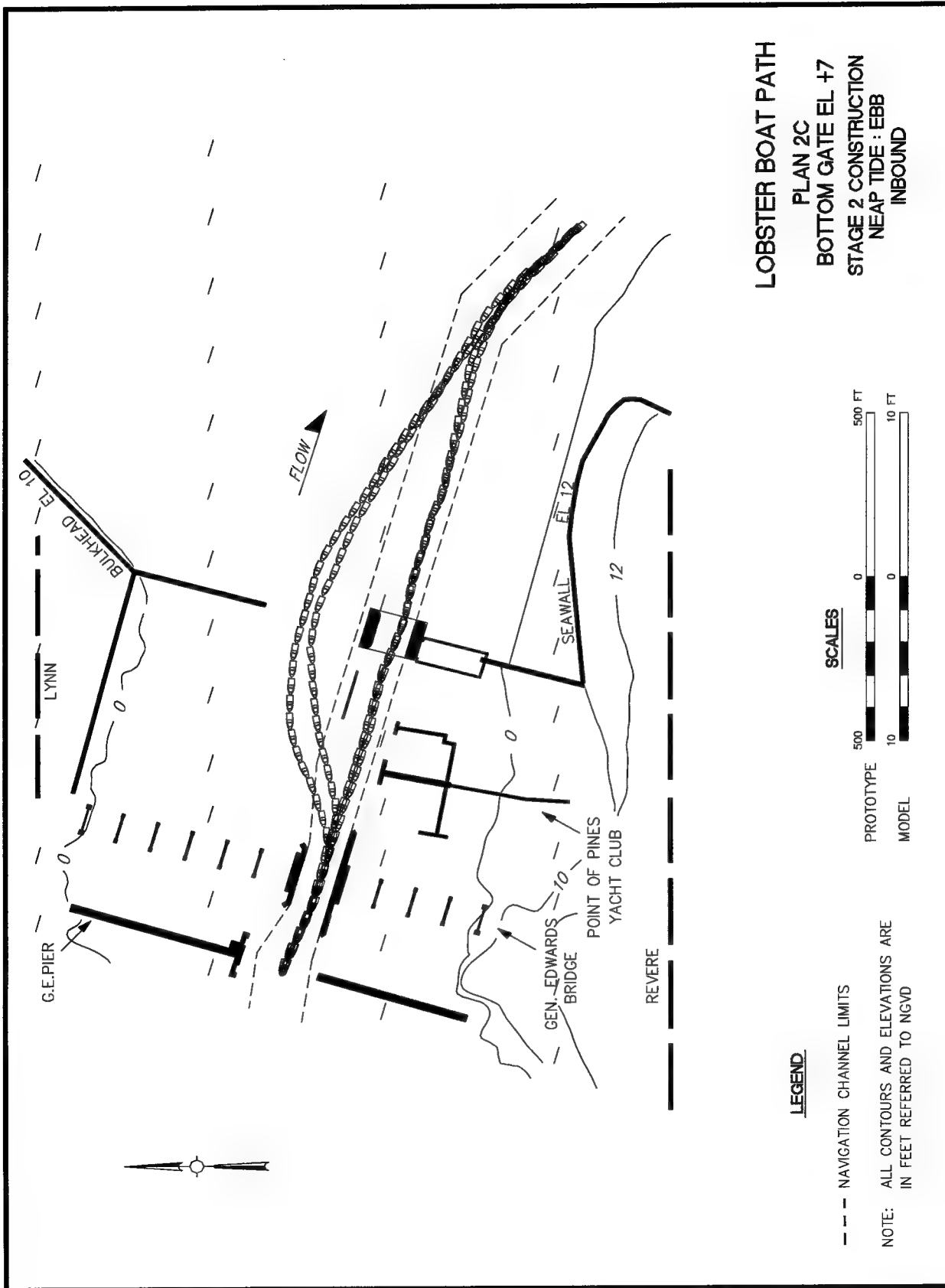
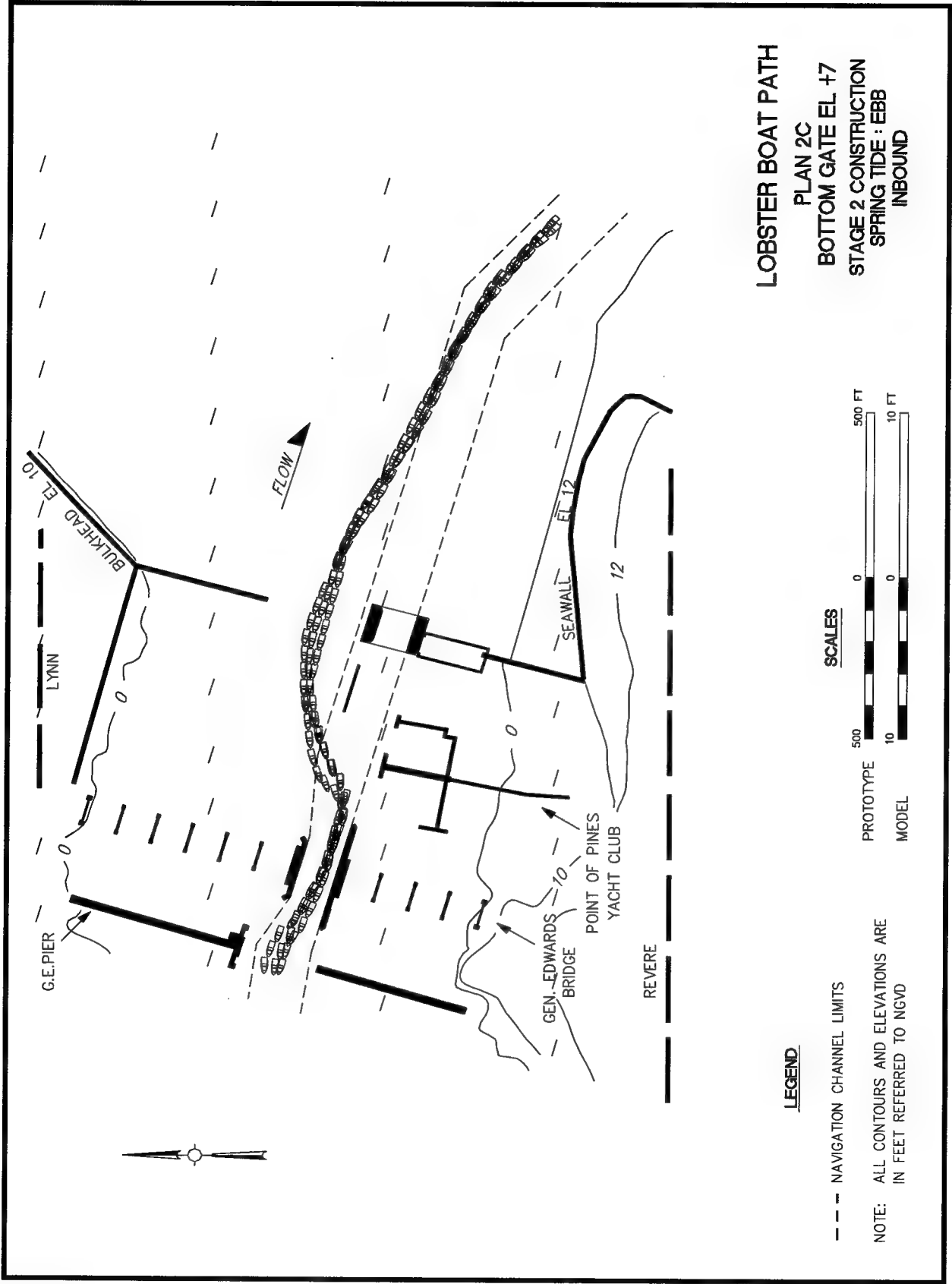


Plate 74

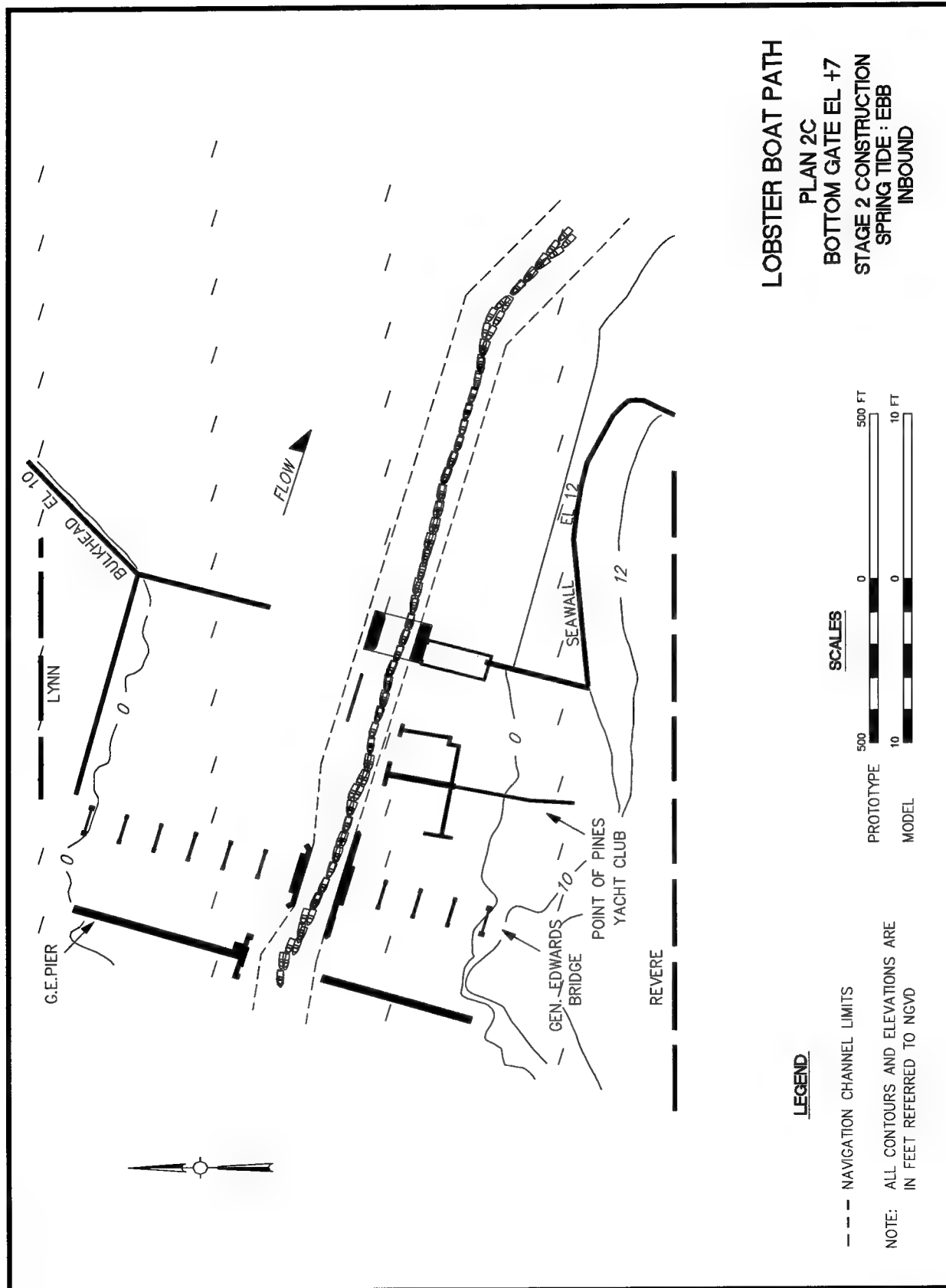




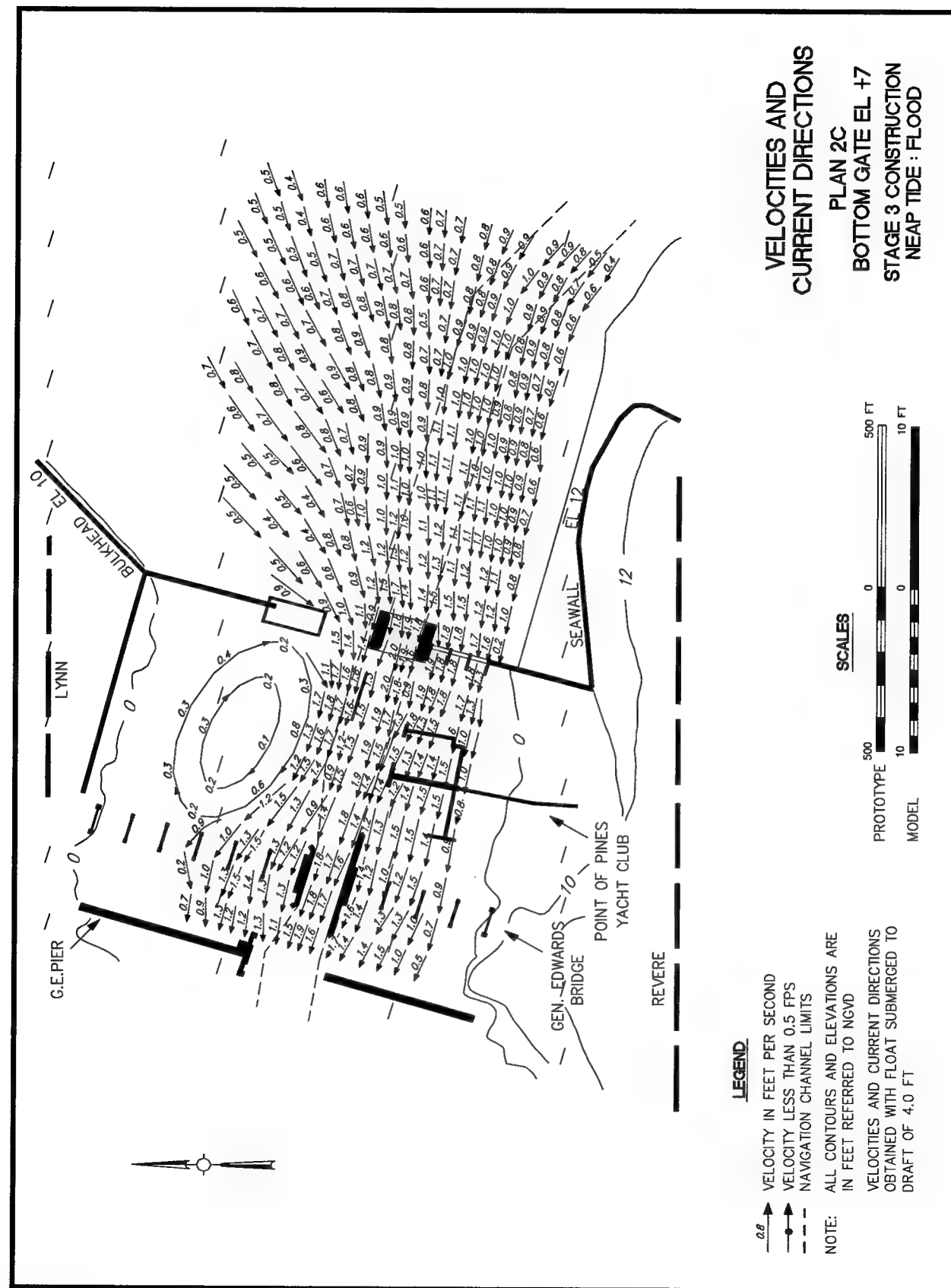
LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL. +7
 STAGE 2 CONSTRUCTION
 SPRING TIDE : EBB
 INBOUND

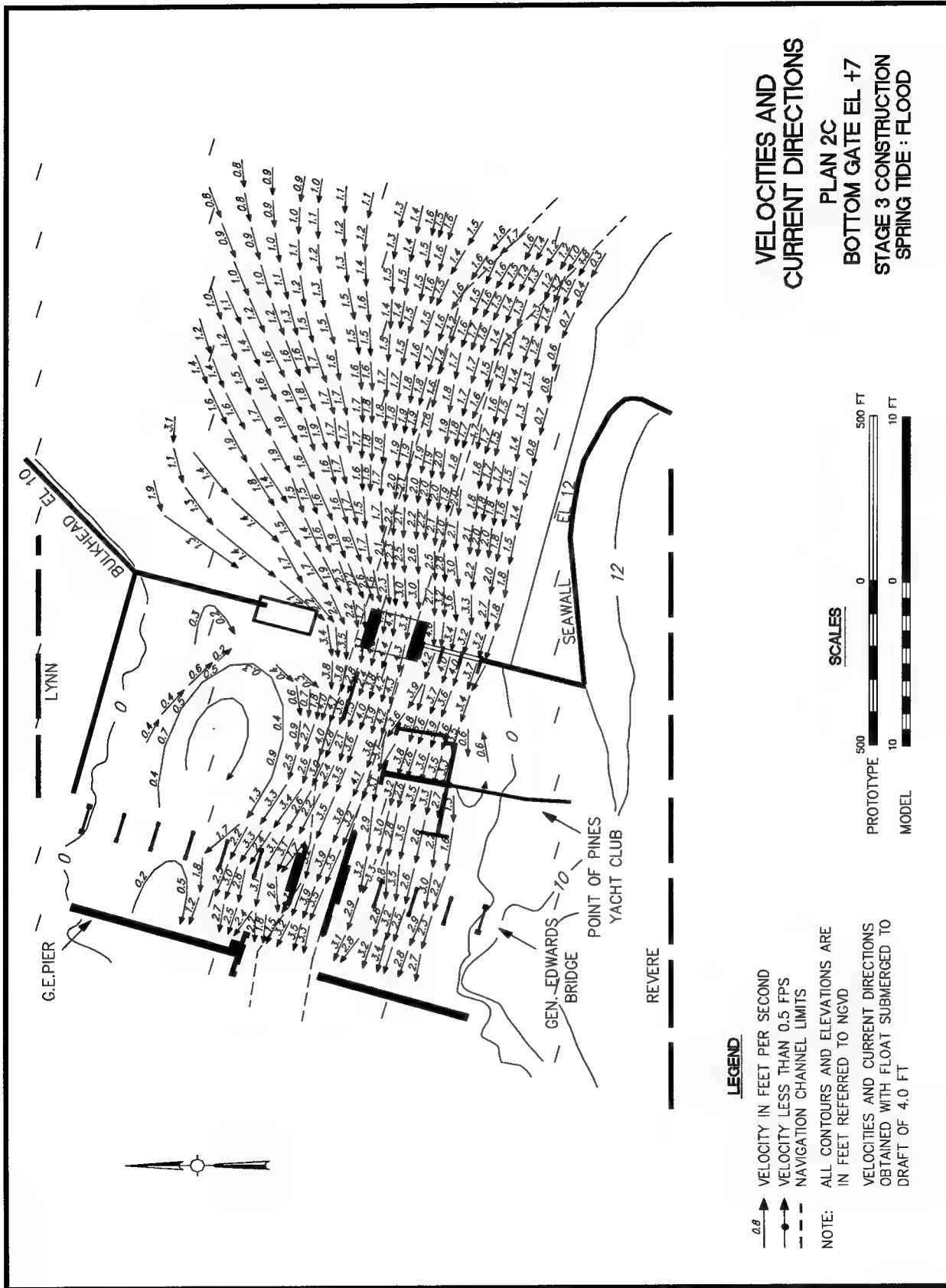


Plate 76



LOBSTER BOAT PATH
PLAN 2C
BOTTOM GATE EL +7
STAGE 2 CONSTRUCTION
SPRING TIDE : EBB
INBOUND





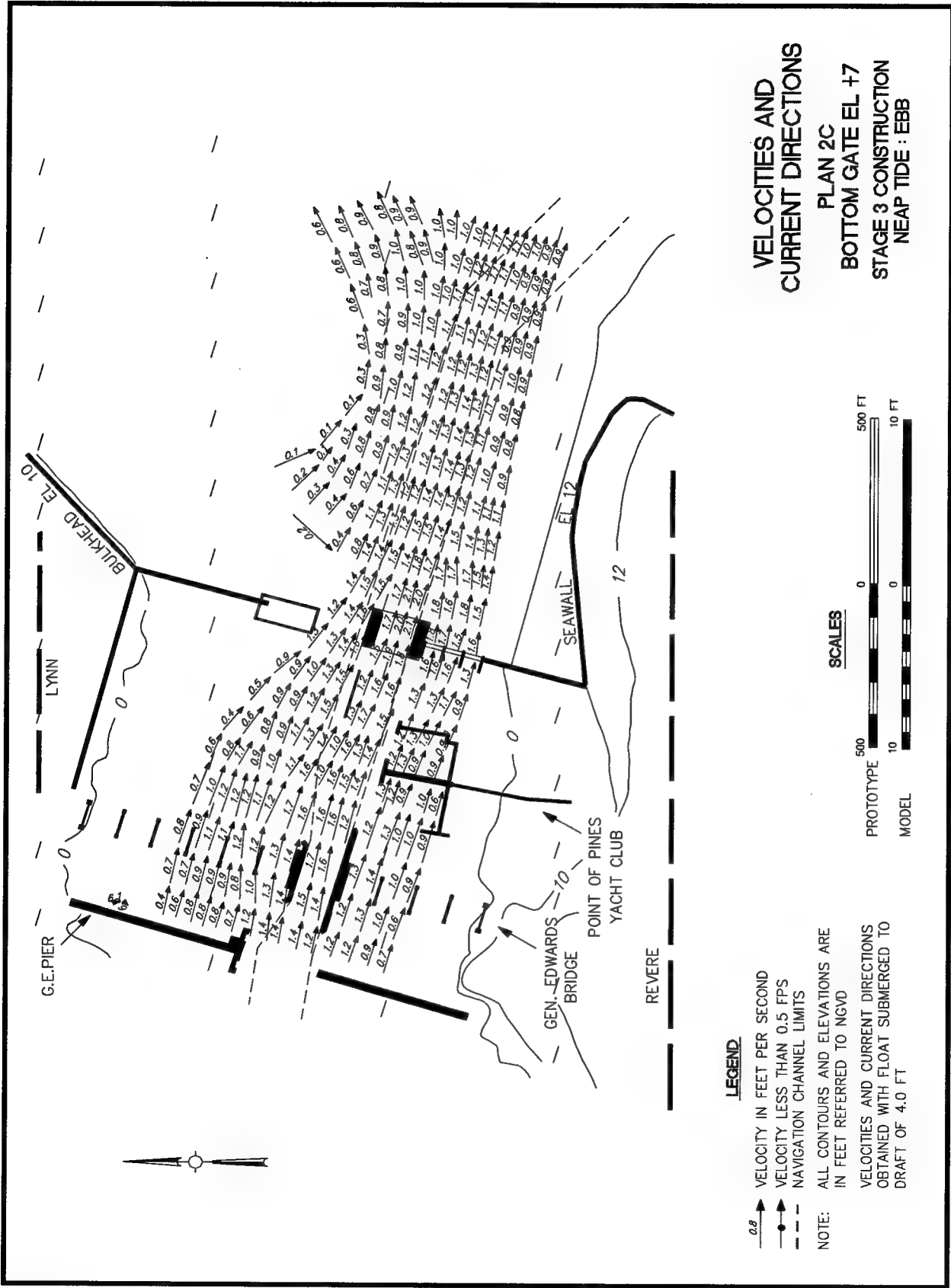
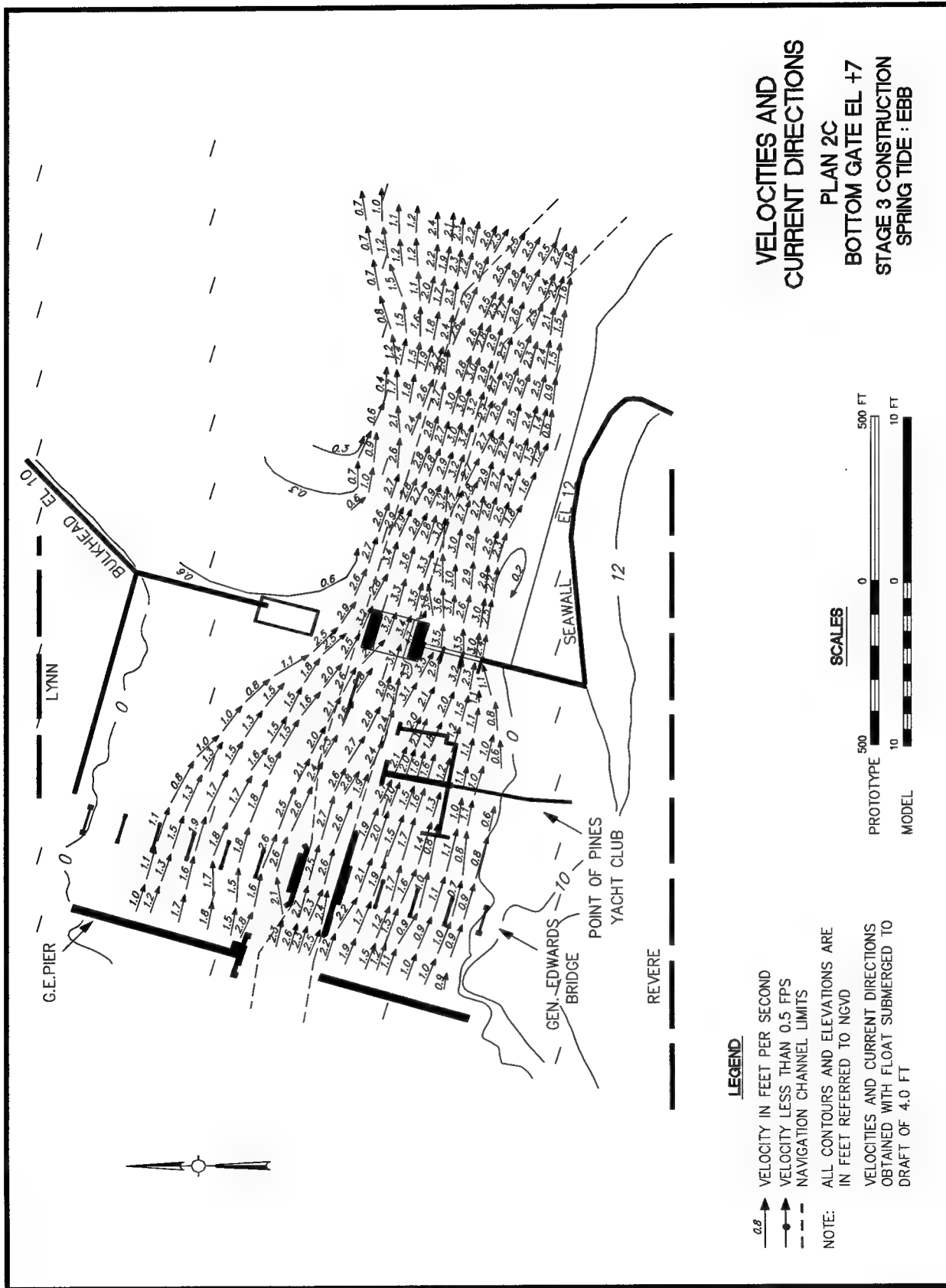


Plate 80



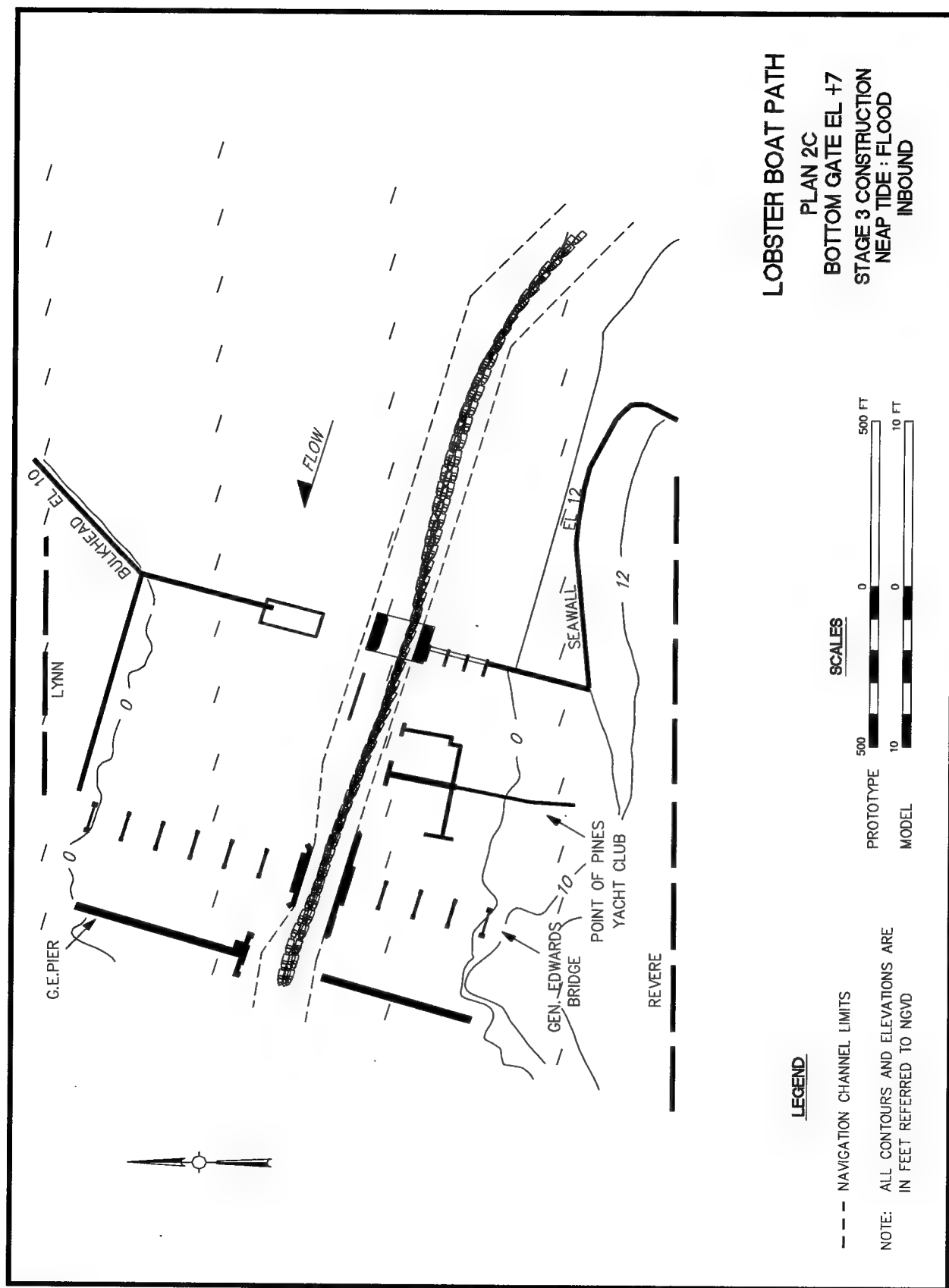
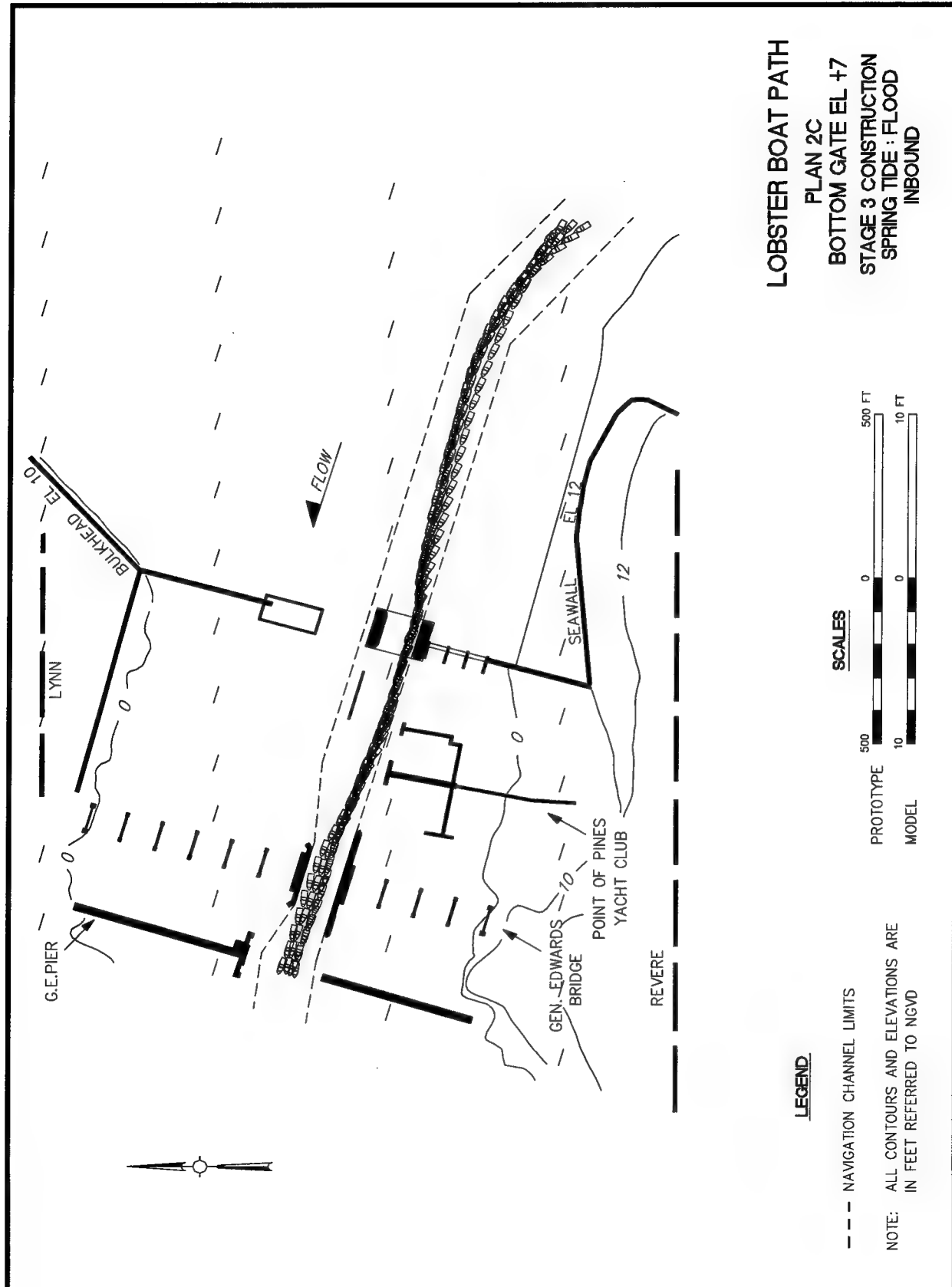


Plate 82



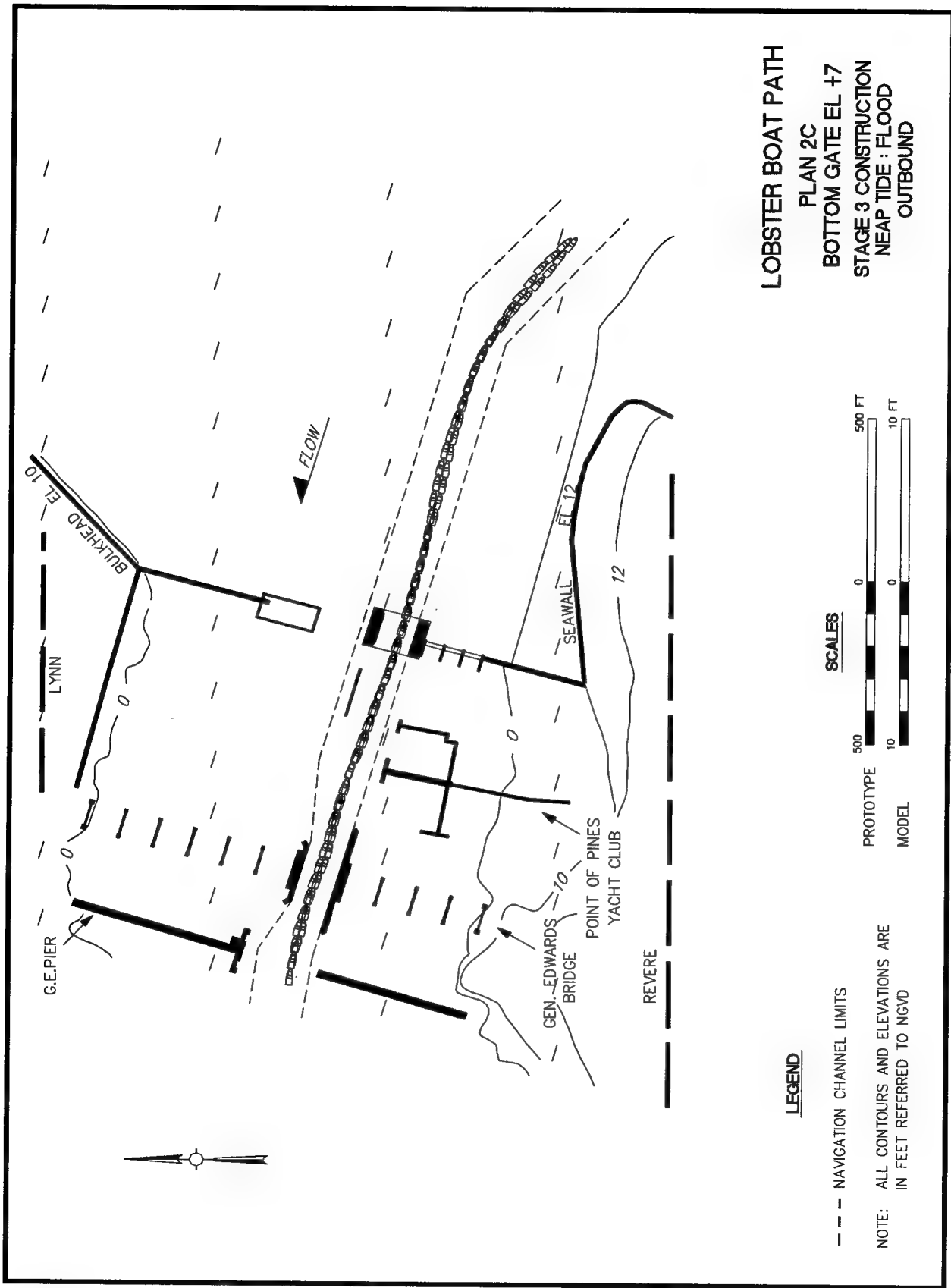
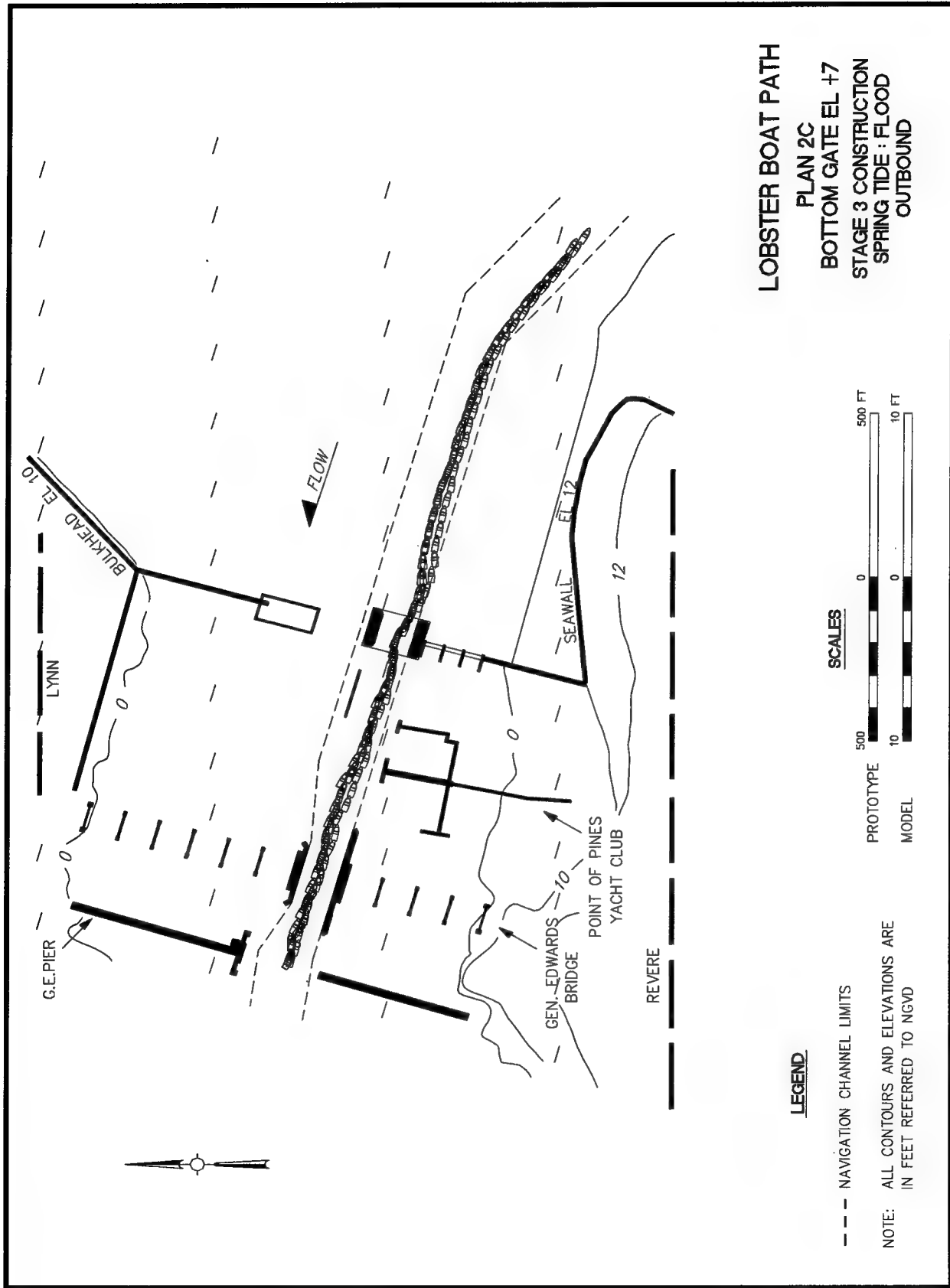


Plate 84



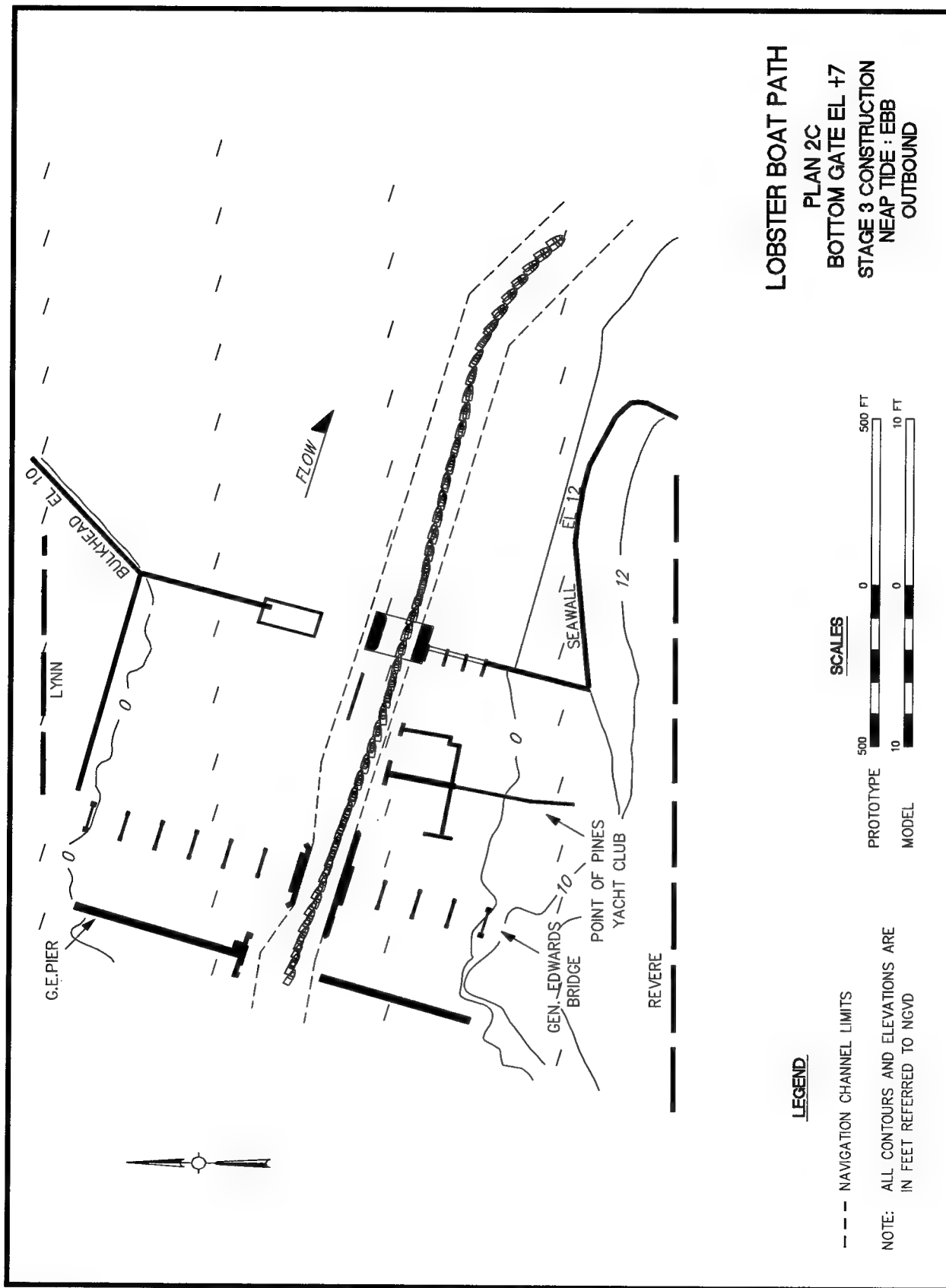
LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL. +7
 STAGE 3 CONSTRUCTION
 SPRING TIDE : FLOOD
 OUTBOUND

LEGEND

-- -- NAVIGATION CHANNEL LIMITS
 NOTE: ALL CONTOURS AND ELEVATIONS ARE
 IN FEET REFERRED TO NGVD

SCALES





LOBSTER BOAT PATH

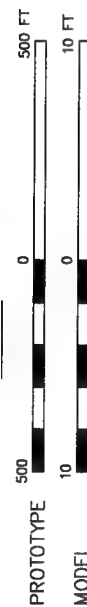
PLAN 2C
 BOTTOM GATE EL +7
 STAGE 3 CONSTRUCTION
 NEAP TIDE : EBB
 OUTBOUND

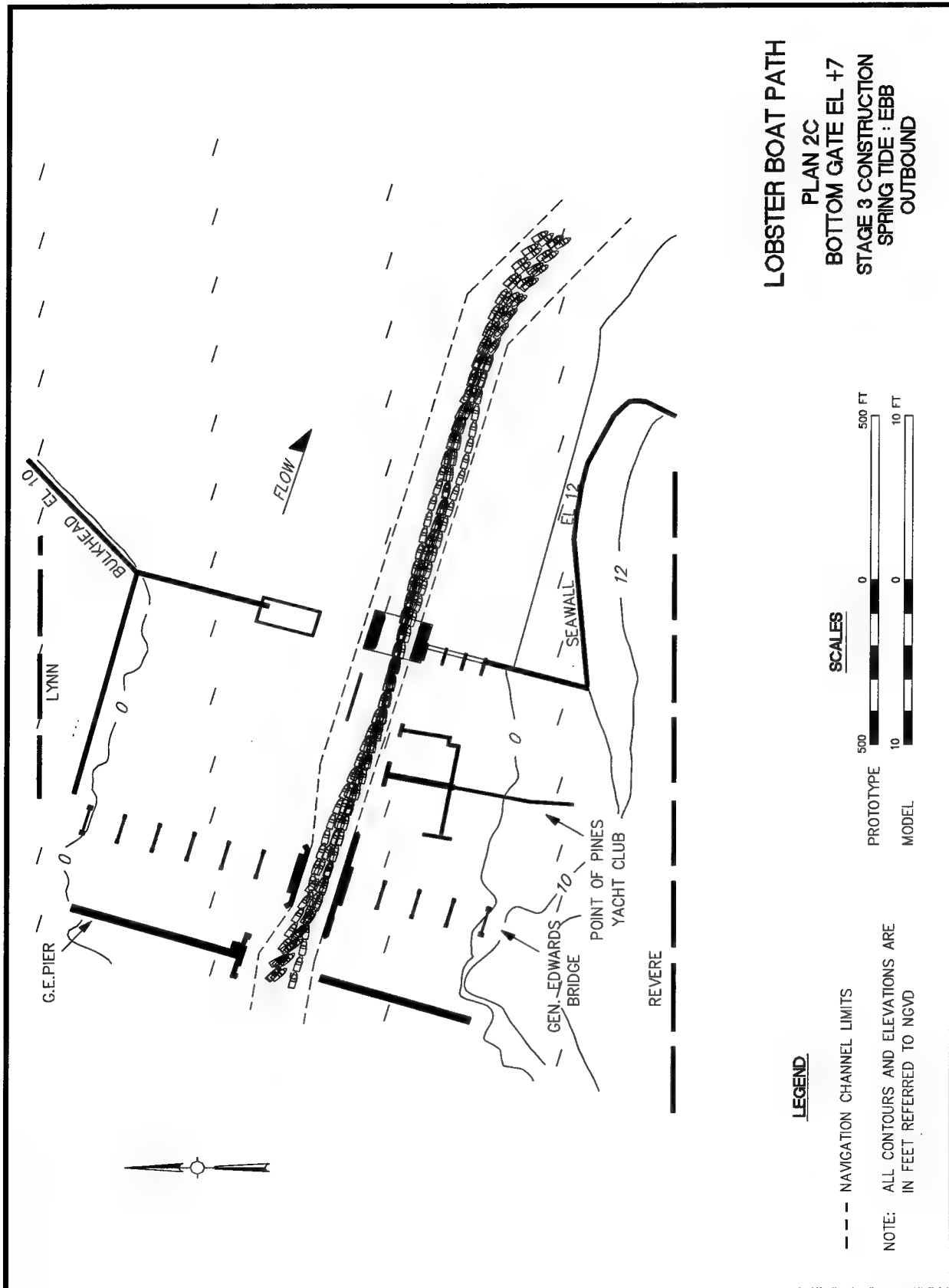
LEGEND

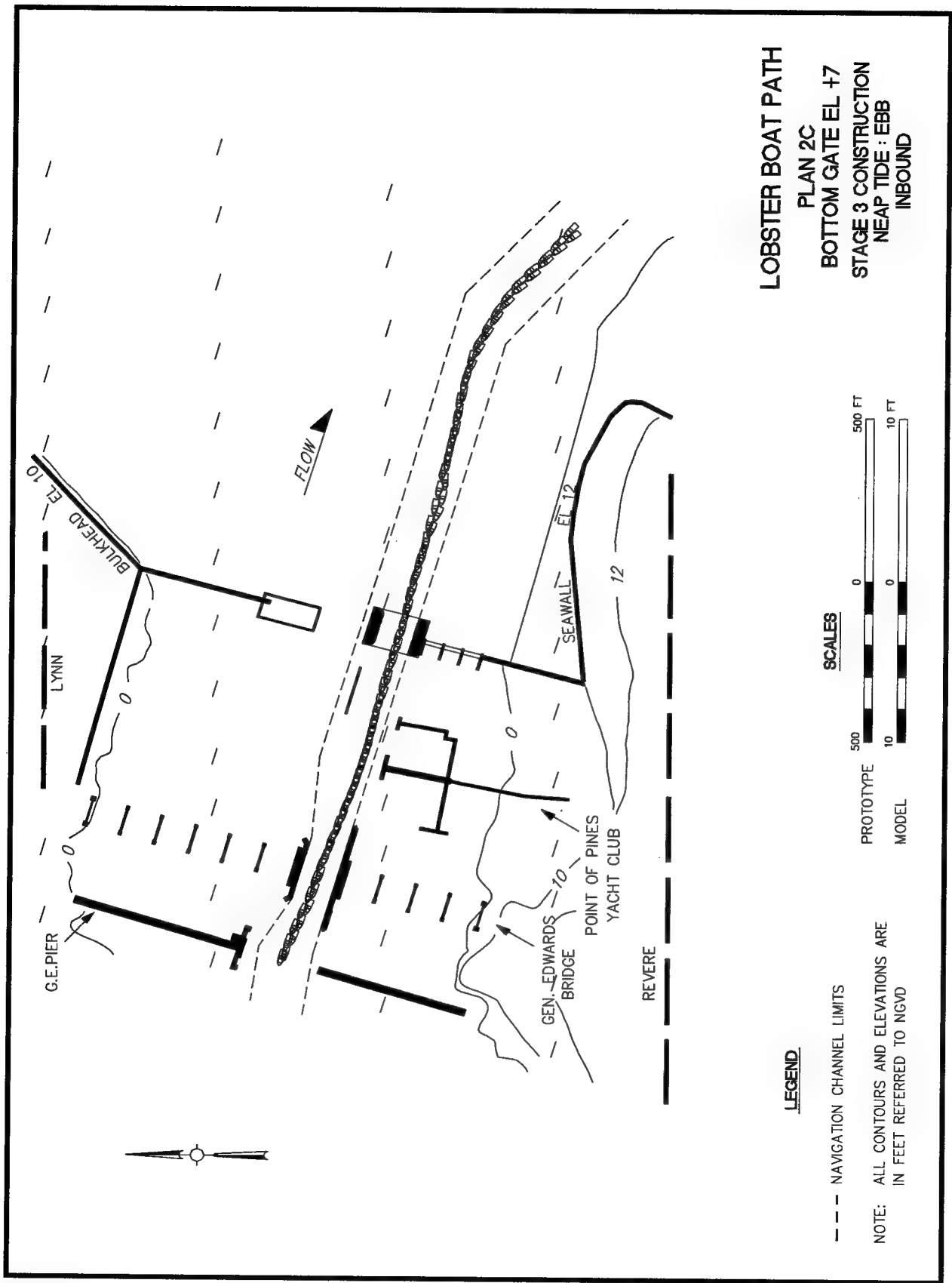
--- NAVIGATION CHANNEL LIMITS

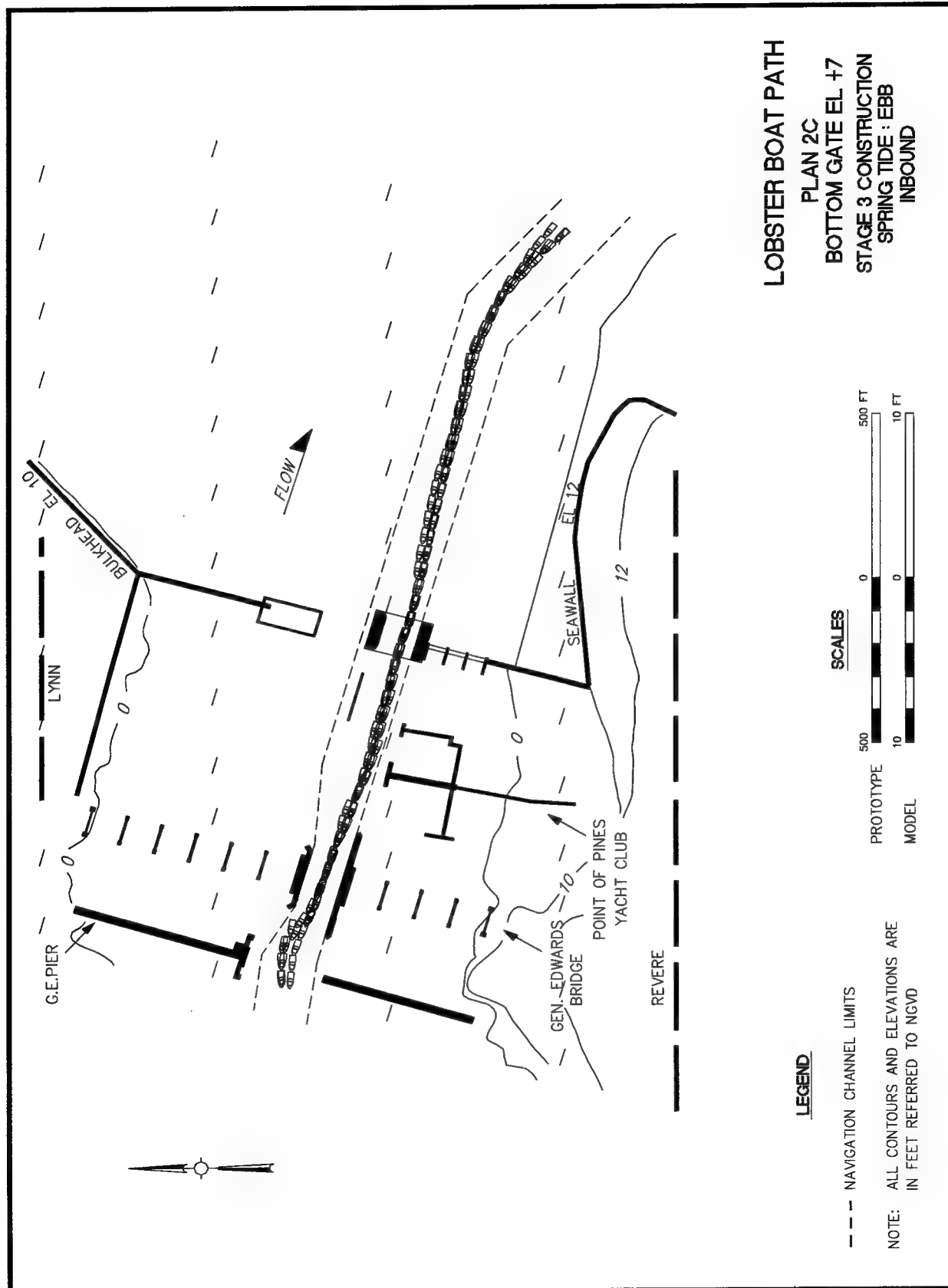
NOTE: ALL CONTOURS AND ELEVATIONS ARE
 IN FEET REFERRED TO NGVD

SCALES

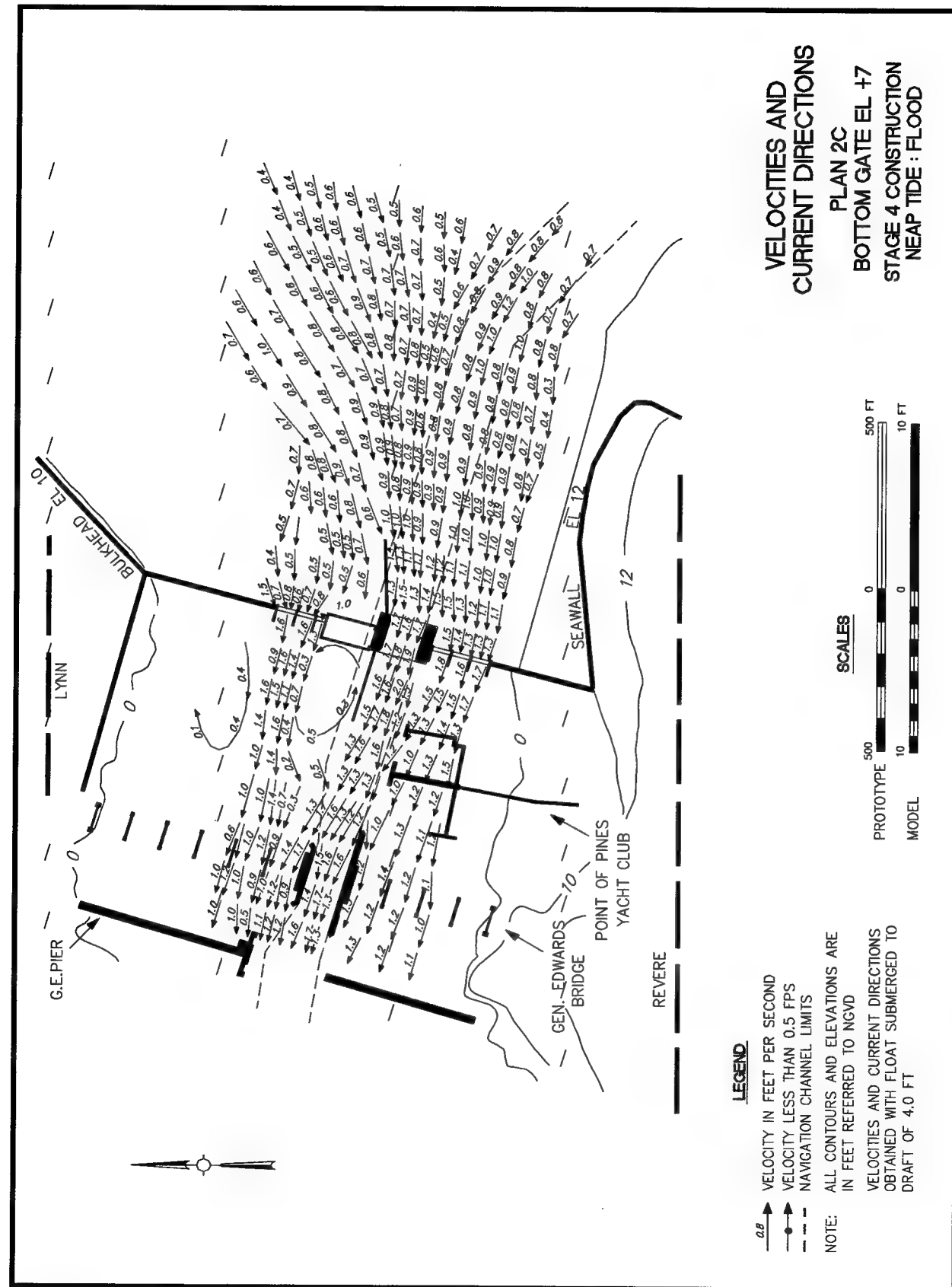


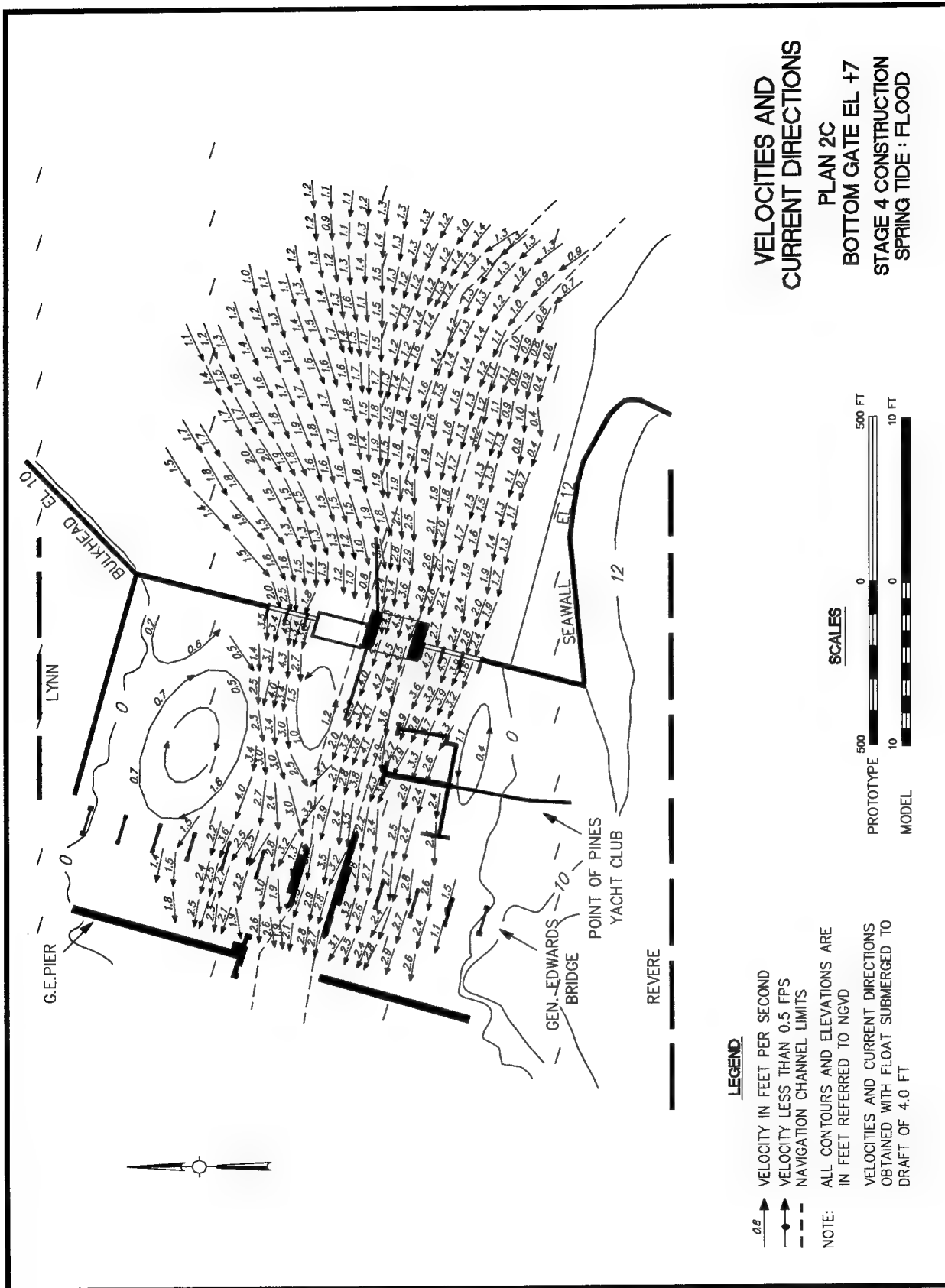


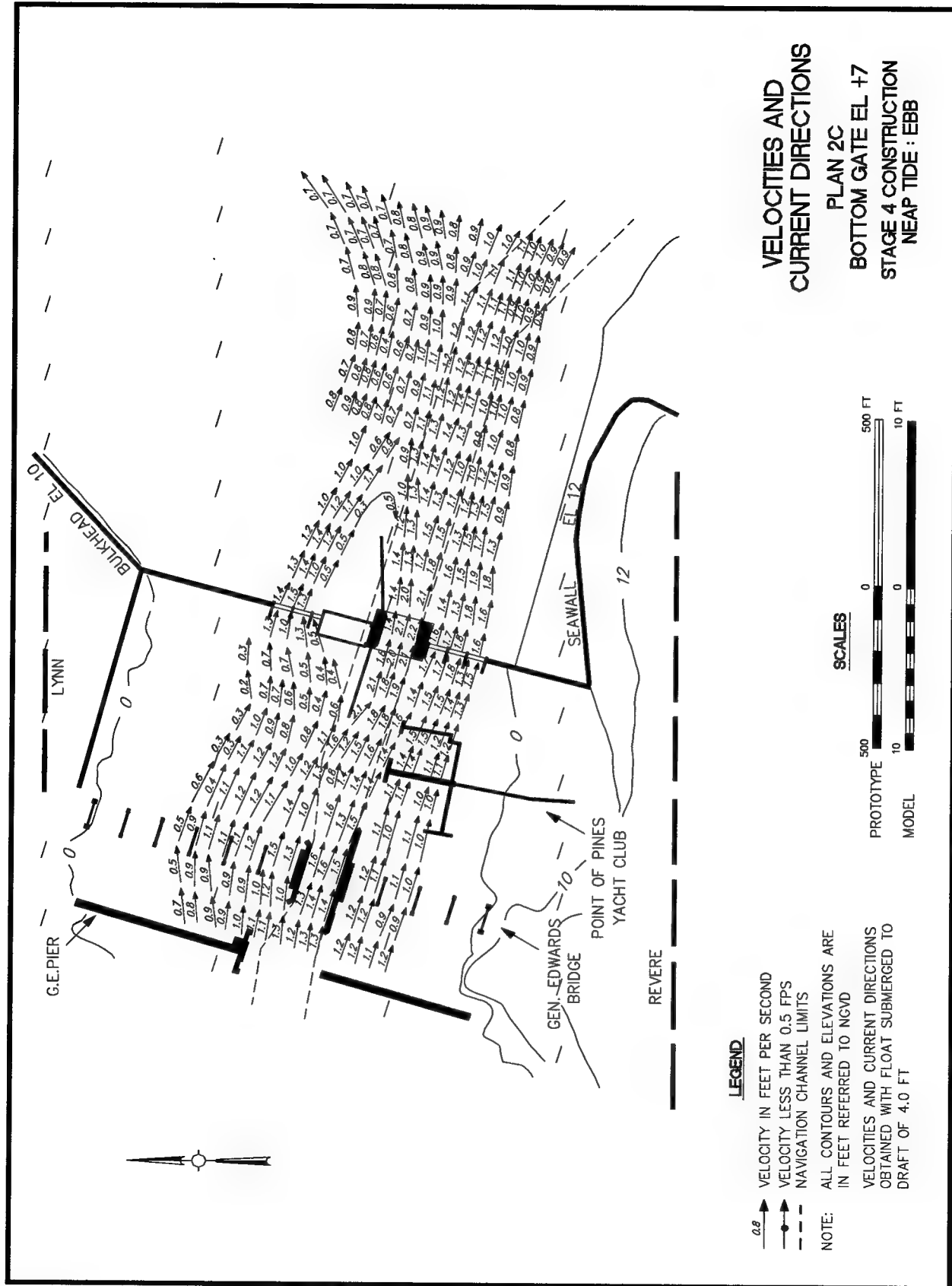


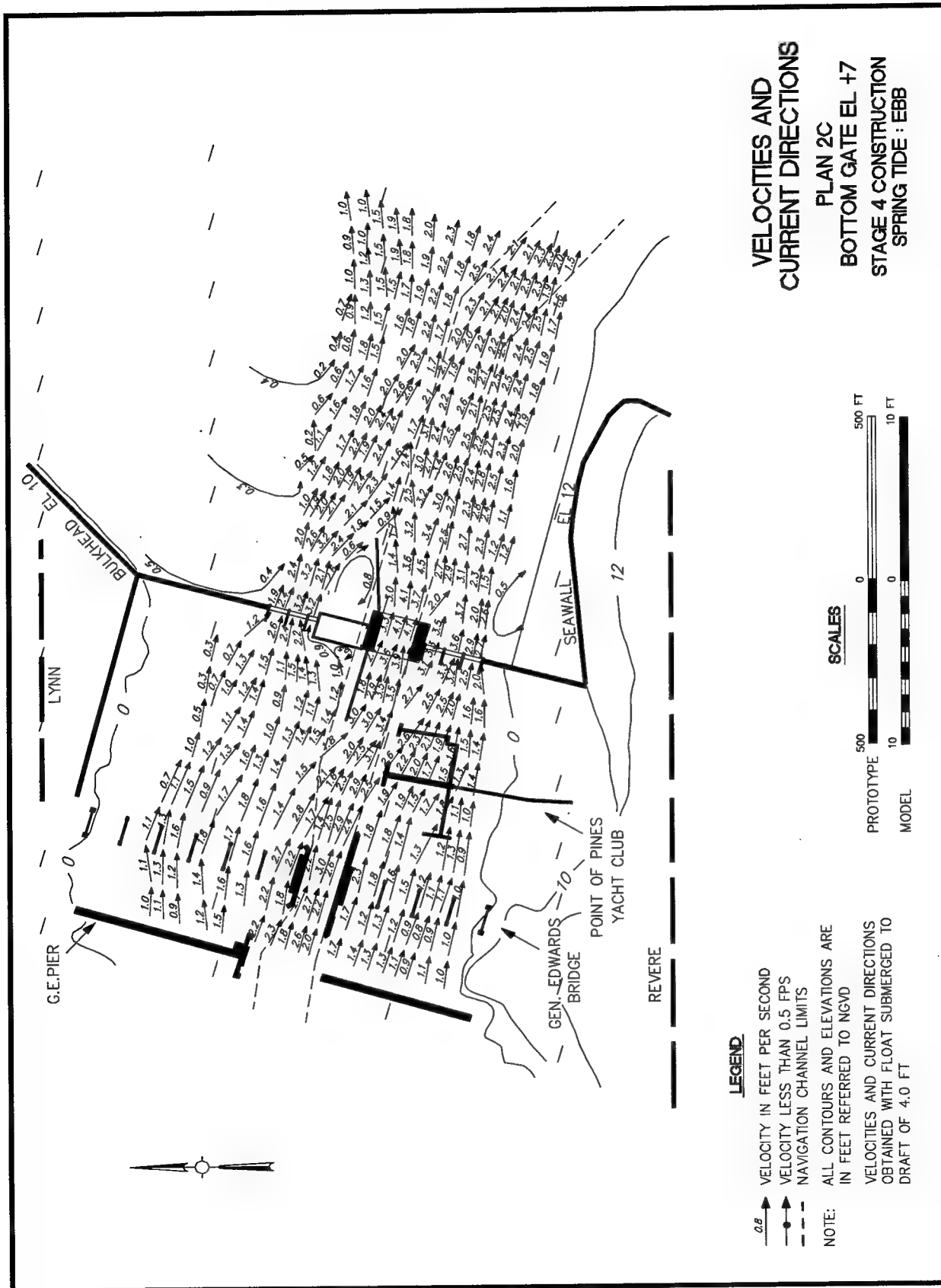


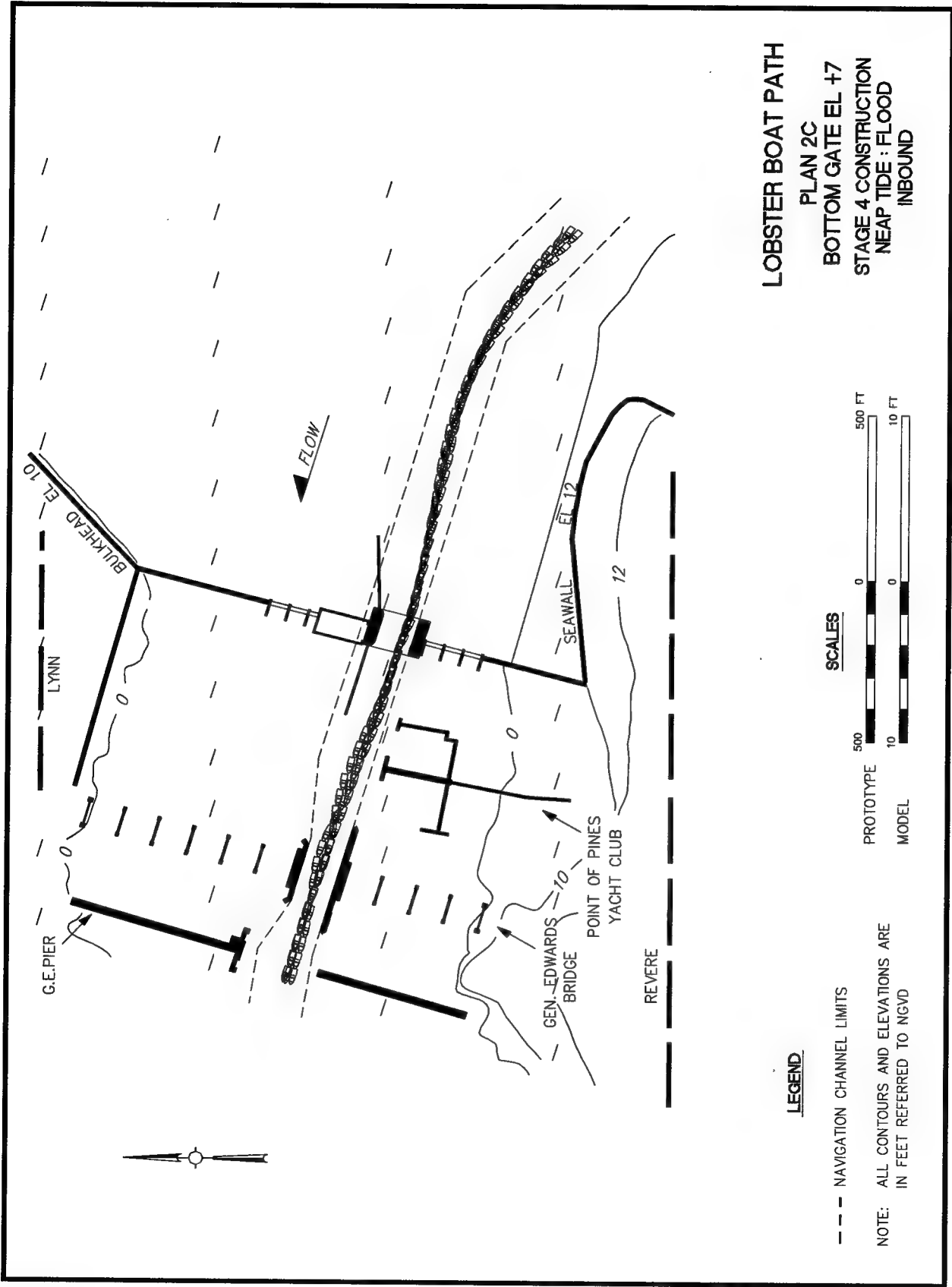
LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL +7
 STAGE 3 CONSTRUCTION
 SPRING TIDE : EBB
 INBOUND





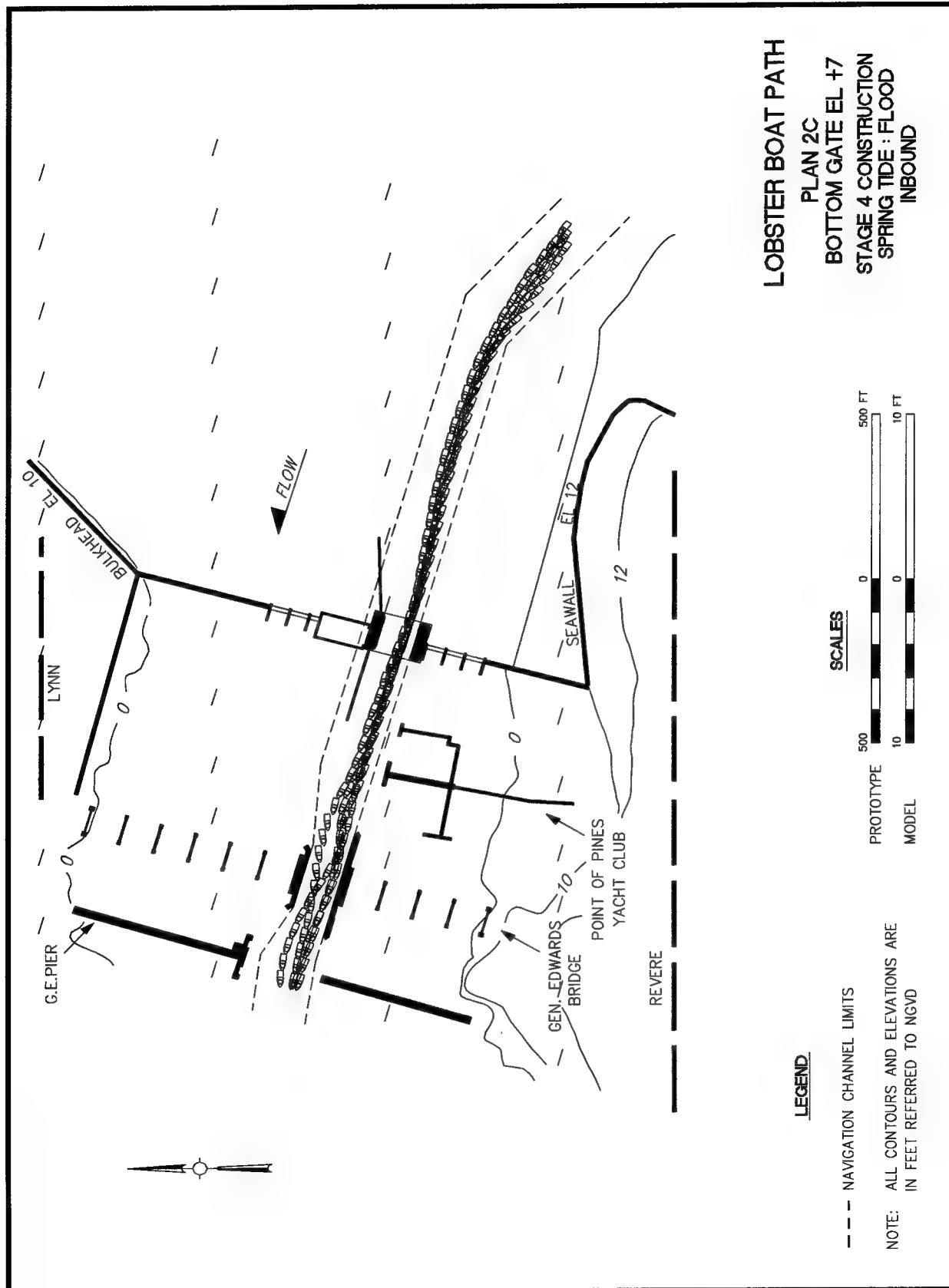


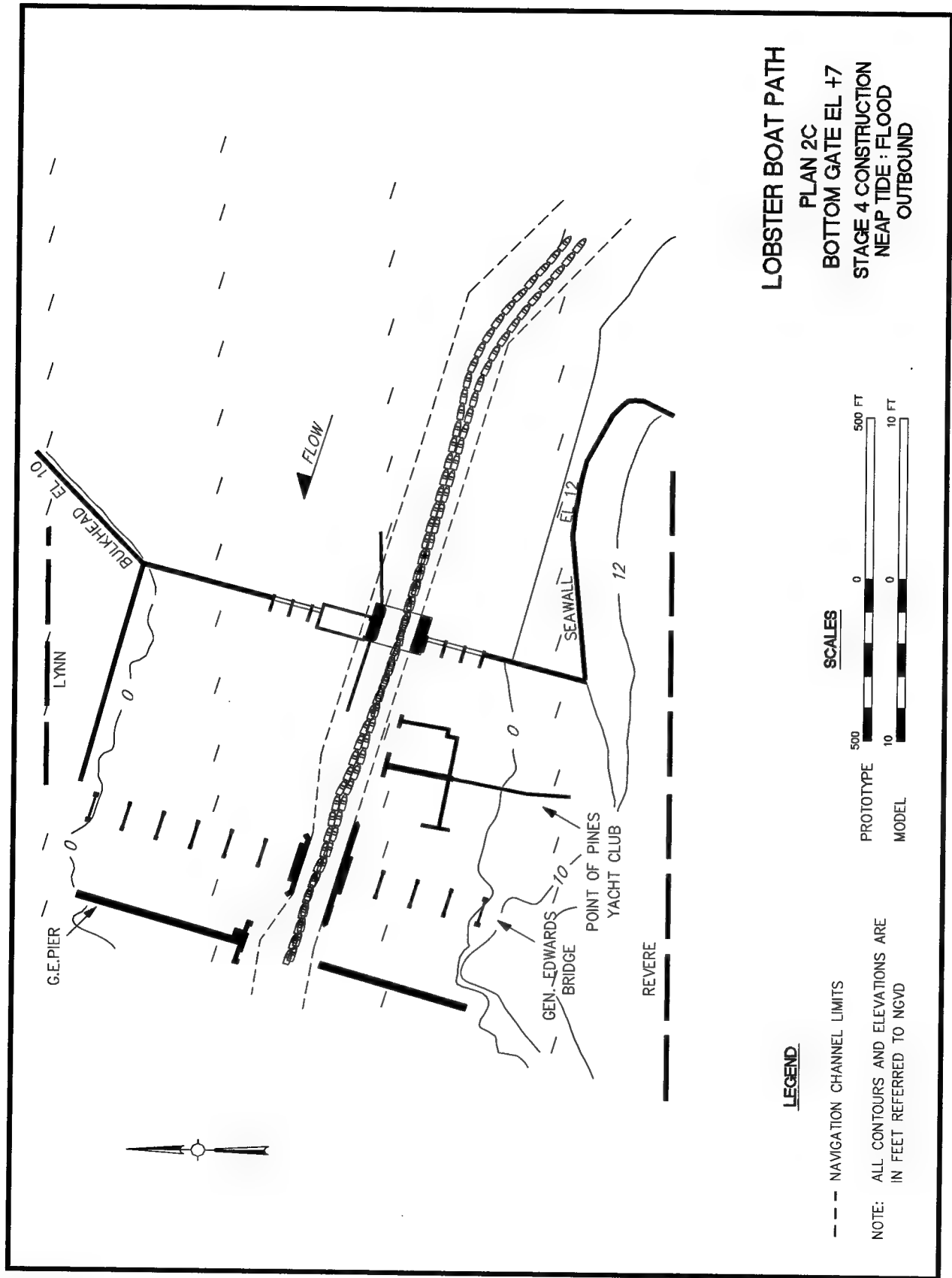




LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL +7
 STAGE 4 CONSTRUCTION
 NEAP TIDE : FLOOD
 INBOUND

Plate 94





LOBSTER BOAT PATH

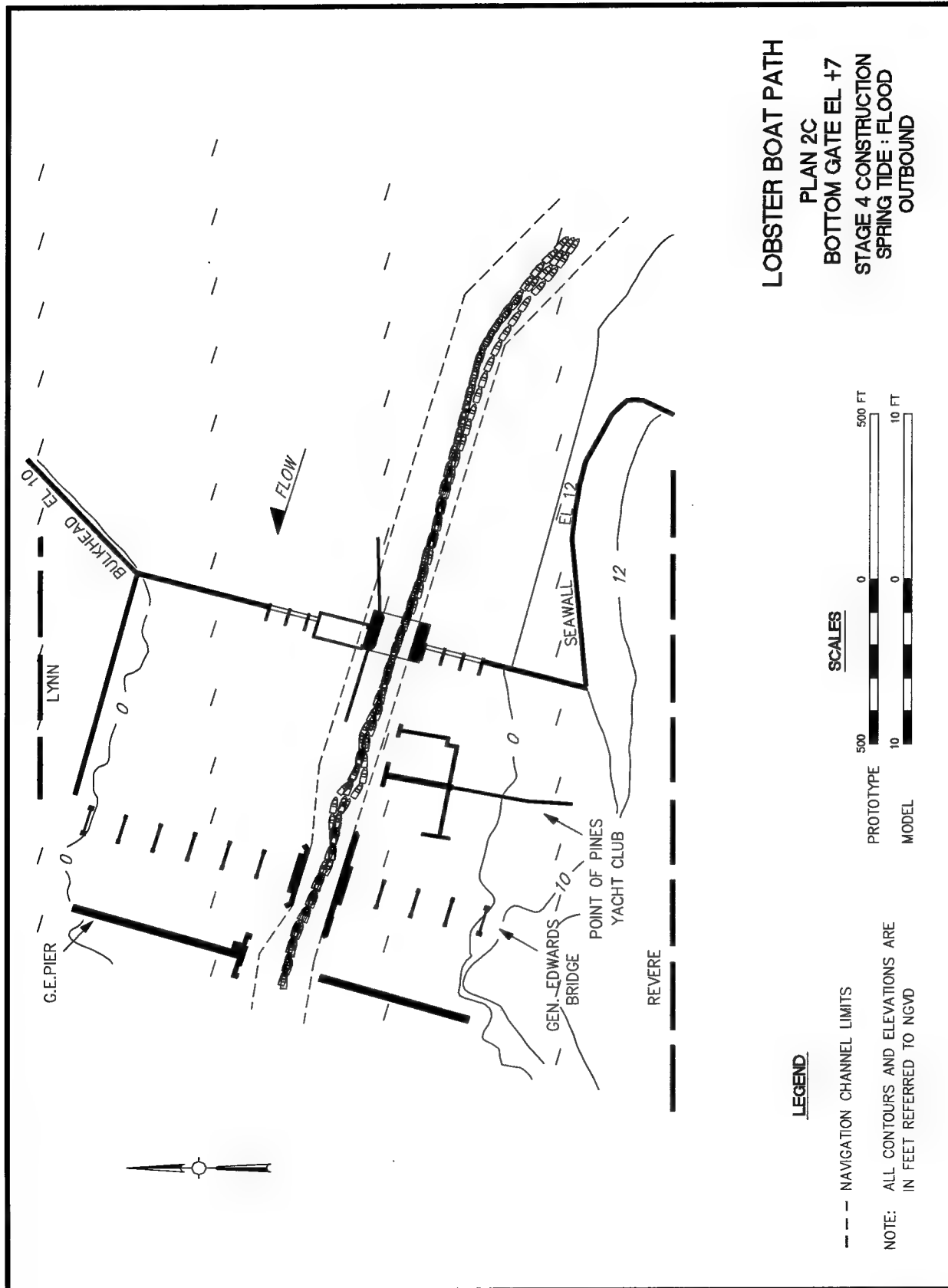
PLAN 2C
 BOTTOM GATE EL +7
 STAGE 4 CONSTRUCTION
 NEAP TIDE : FLOOD
 OUTBOUND



SCALES

LEGEND

--- NAVIGATION CHANNEL LIMITS
 NOTE: ALL CONTOURS AND ELEVATIONS ARE
 IN FEET REFERRED TO NGVD



LOBSTER BOAT PATH

PLAN 2C
 BOTTOM GATE EL +7
 STAGE 4 CONSTRUCTION
 SPRING TIDE : FLOOD
 OUTBOUND

LEGEND

-- -- NAVIGATION CHANNEL LIMITS
 NOTE: ALL CONTOURS AND ELEVATIONS ARE
 IN FEET REFERRED TO NGVD

SCALES



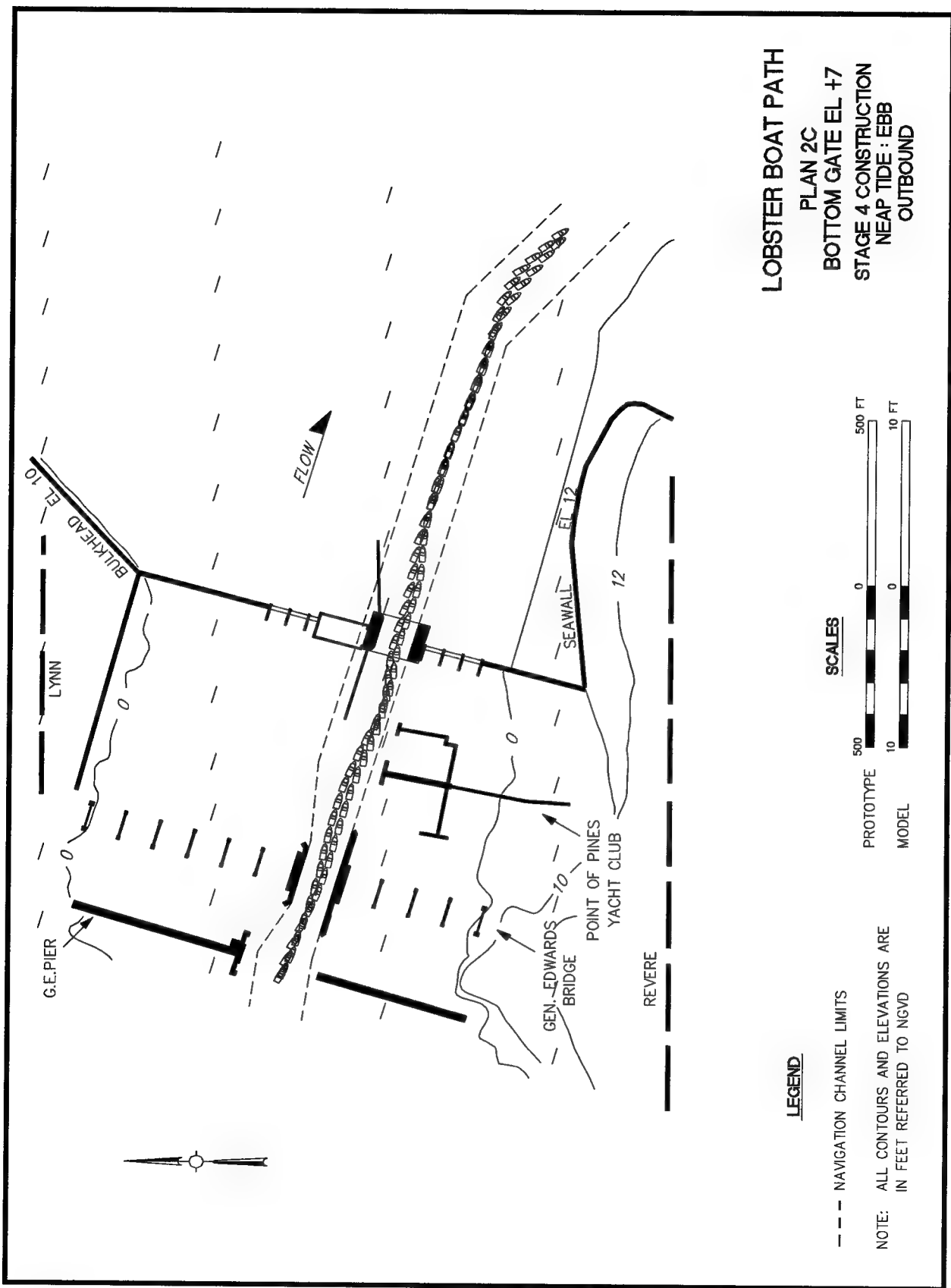
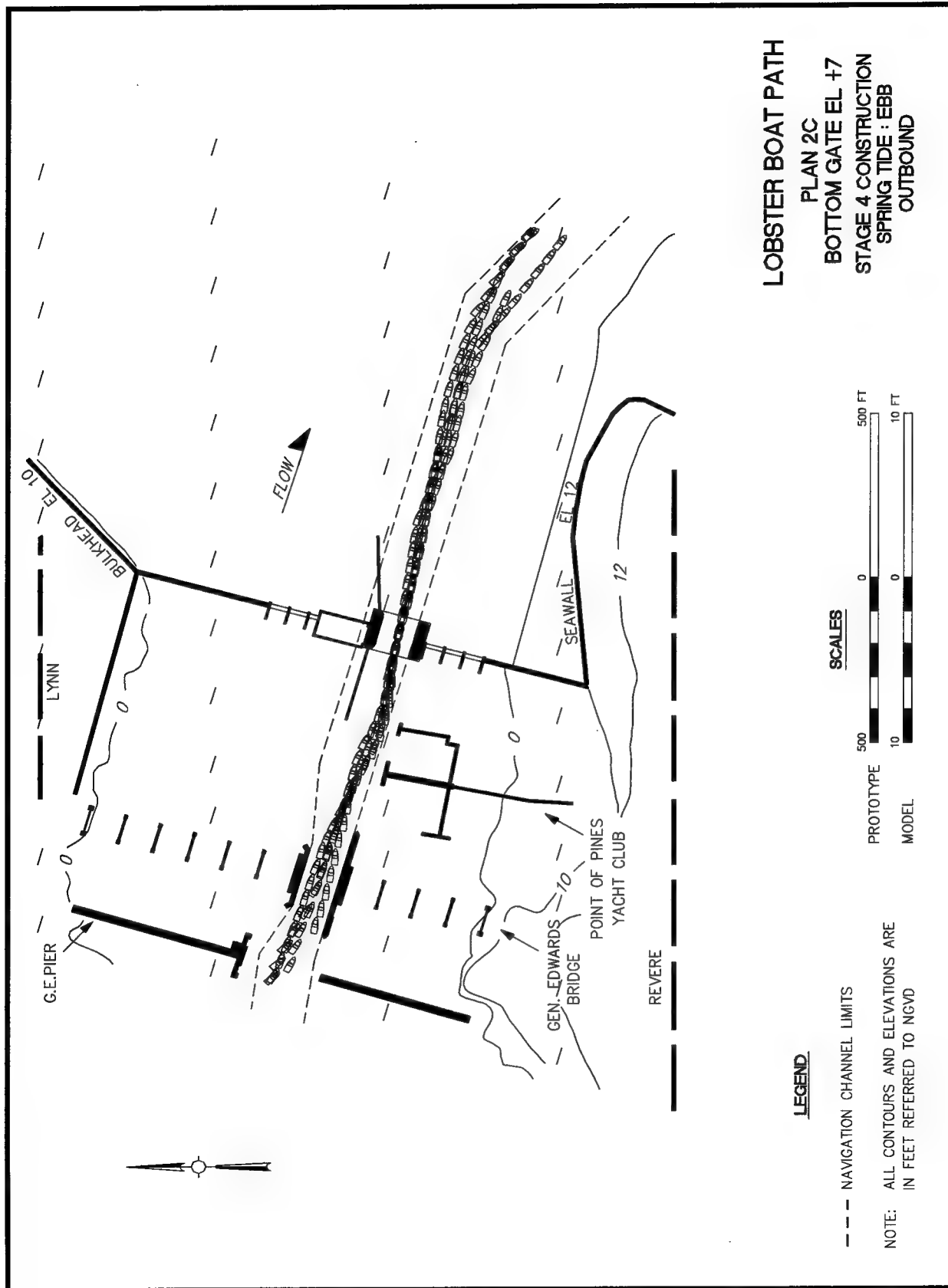
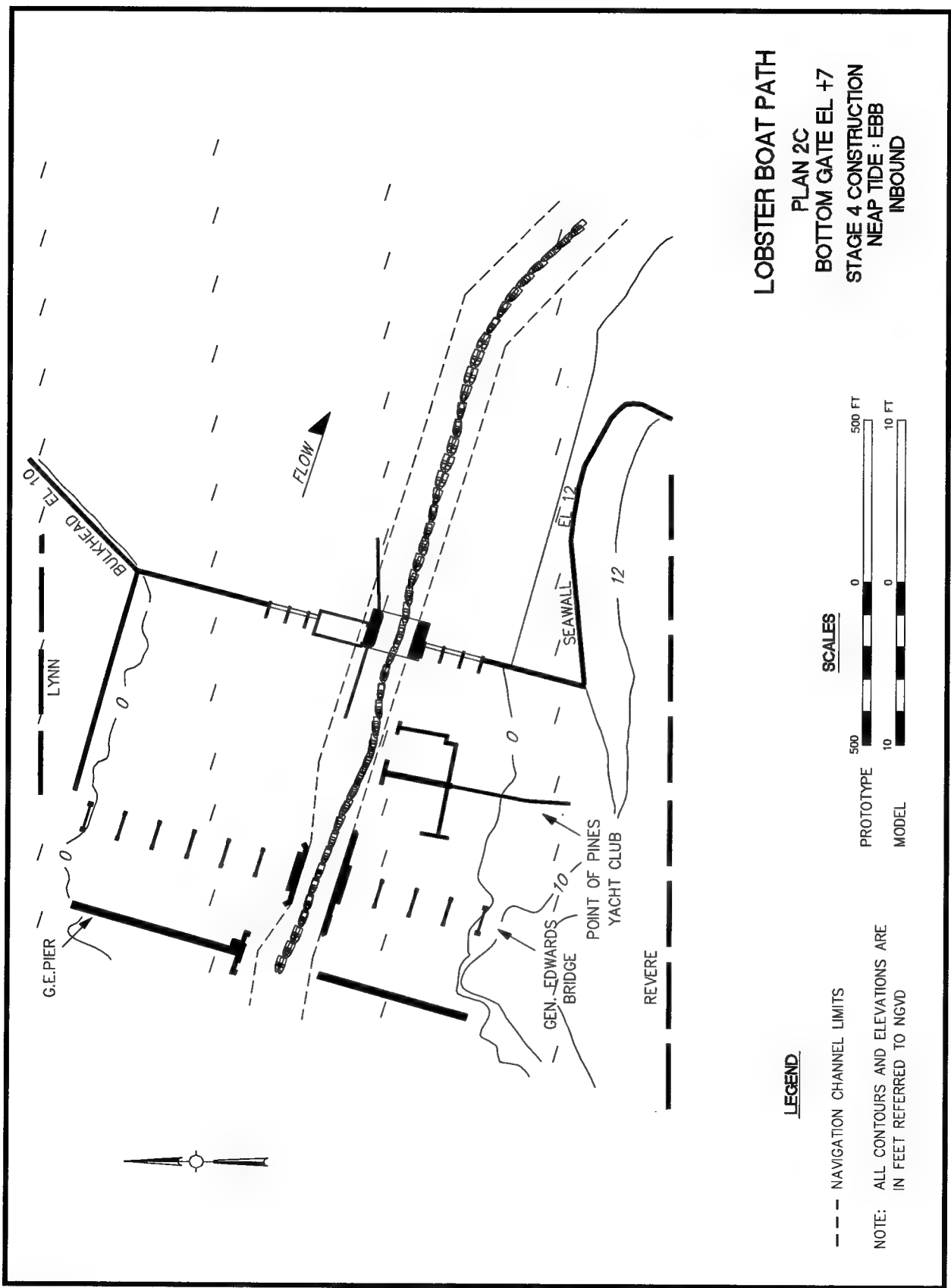
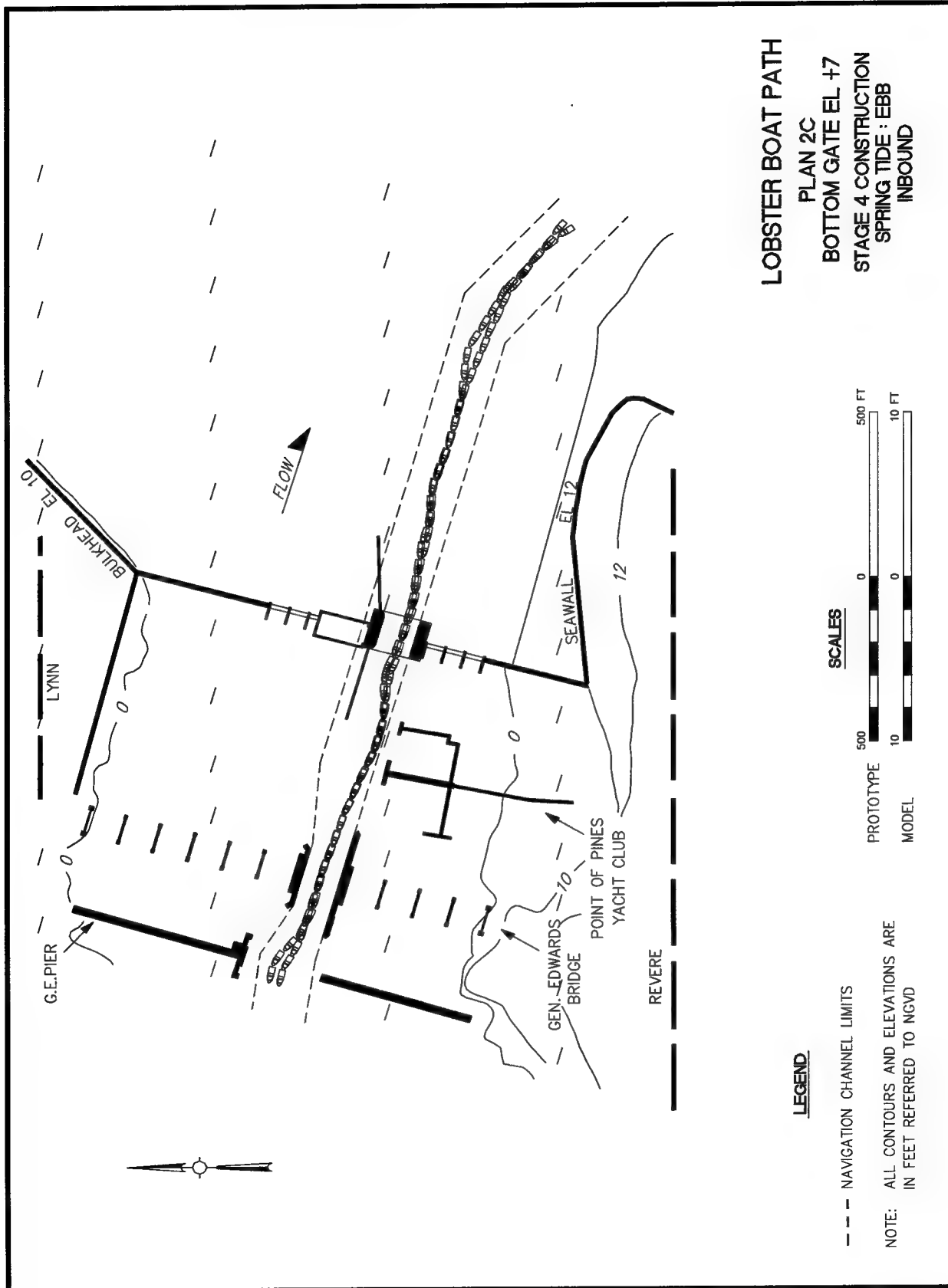
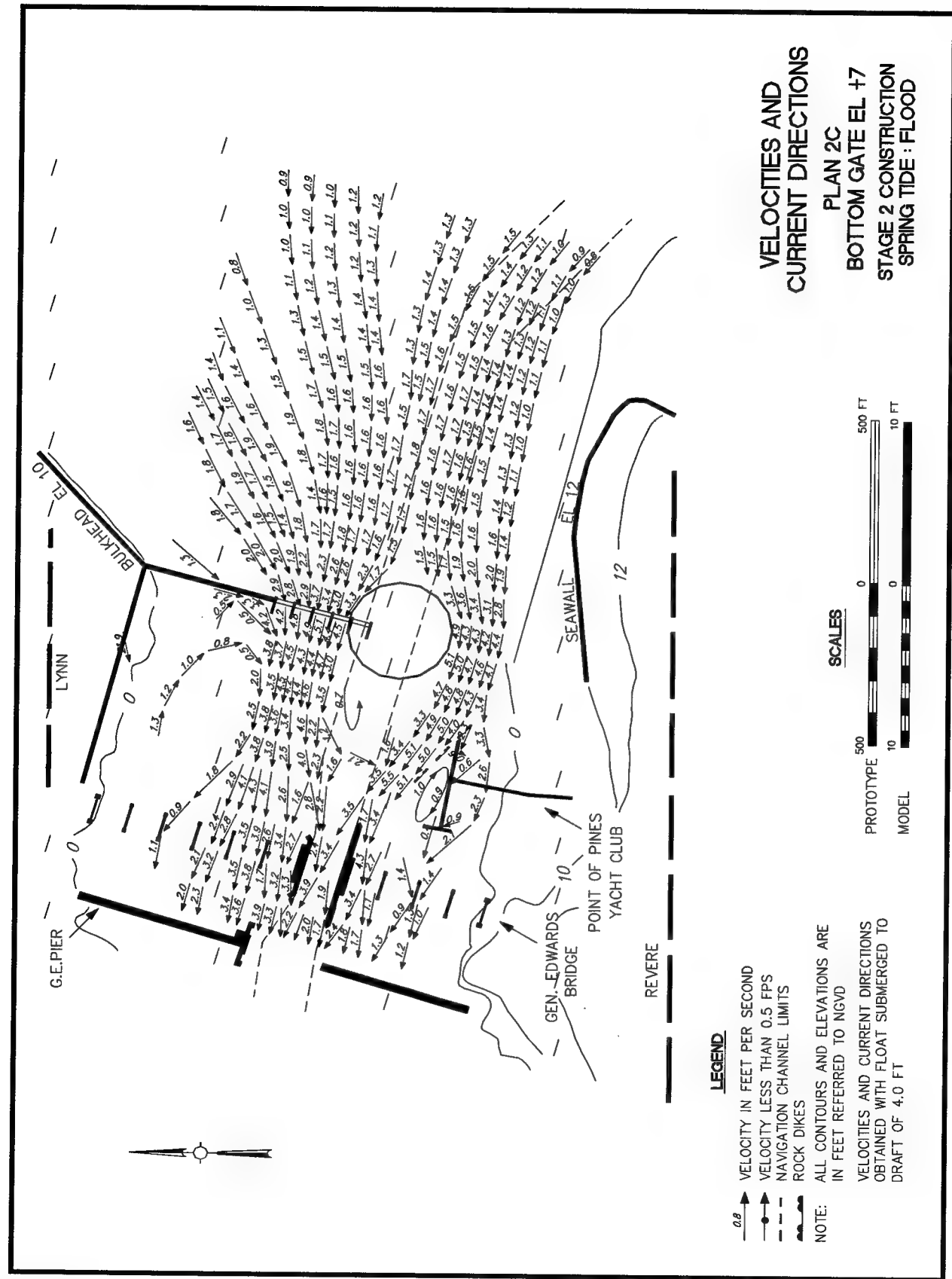


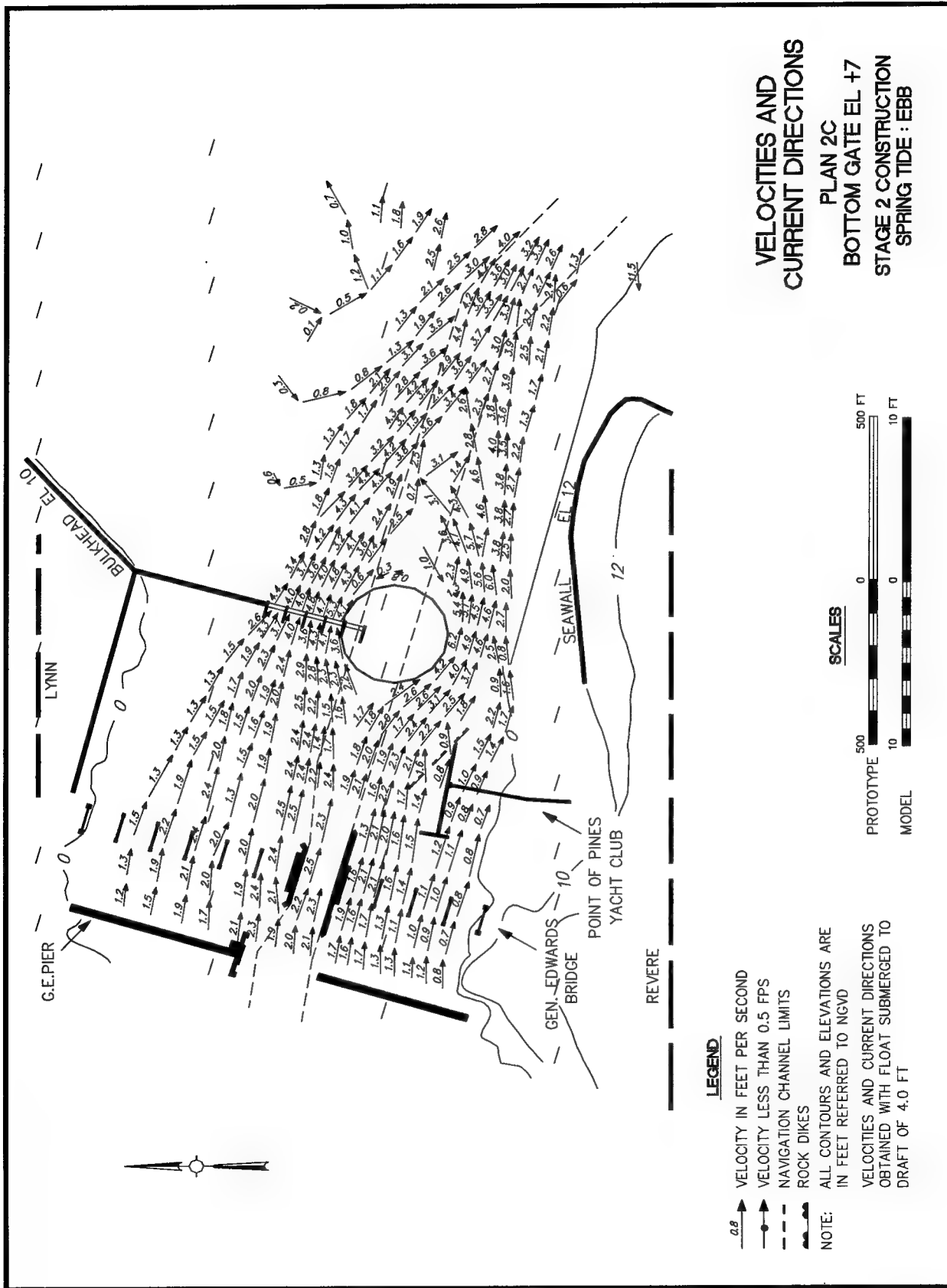
Plate 98











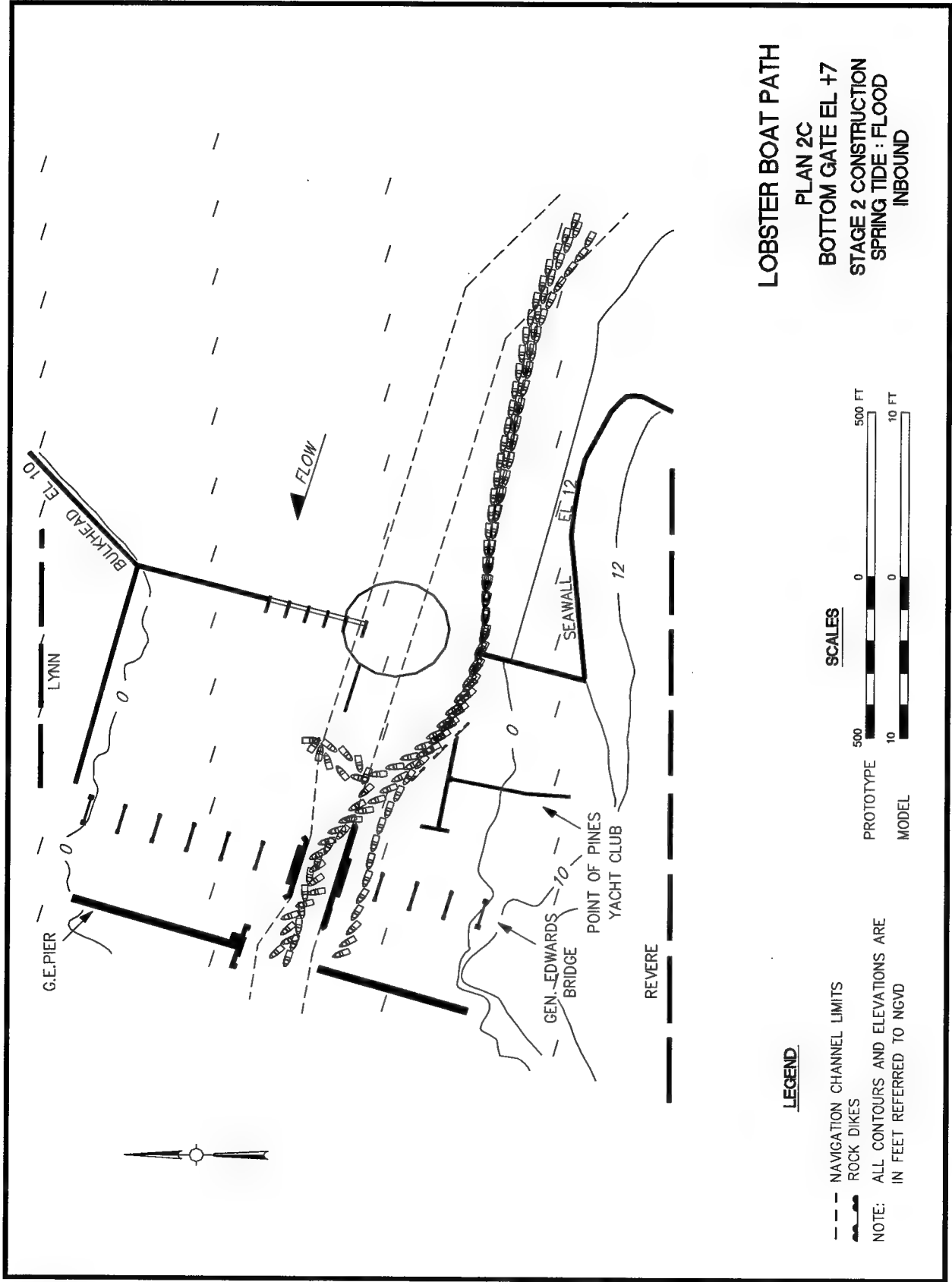
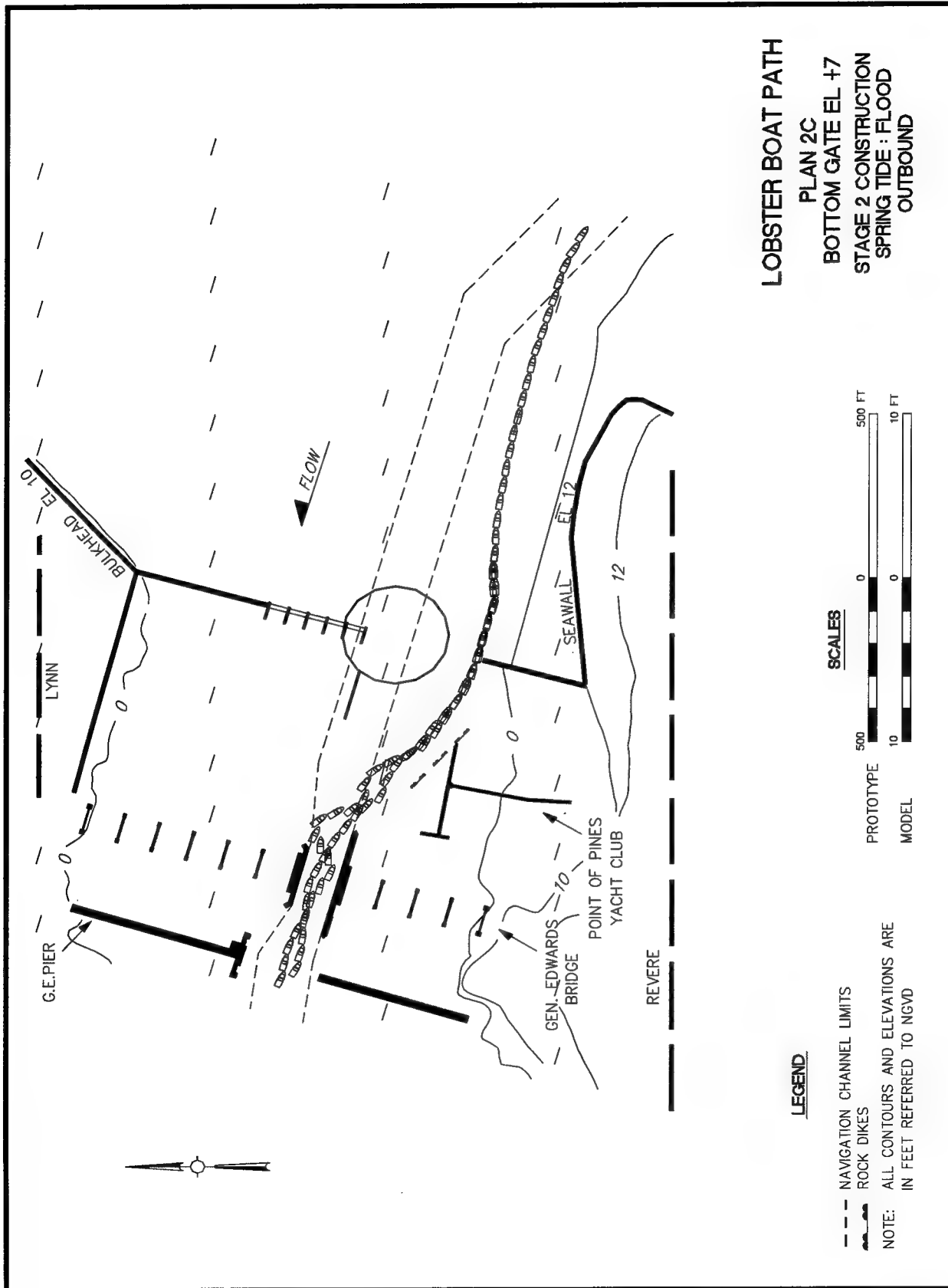
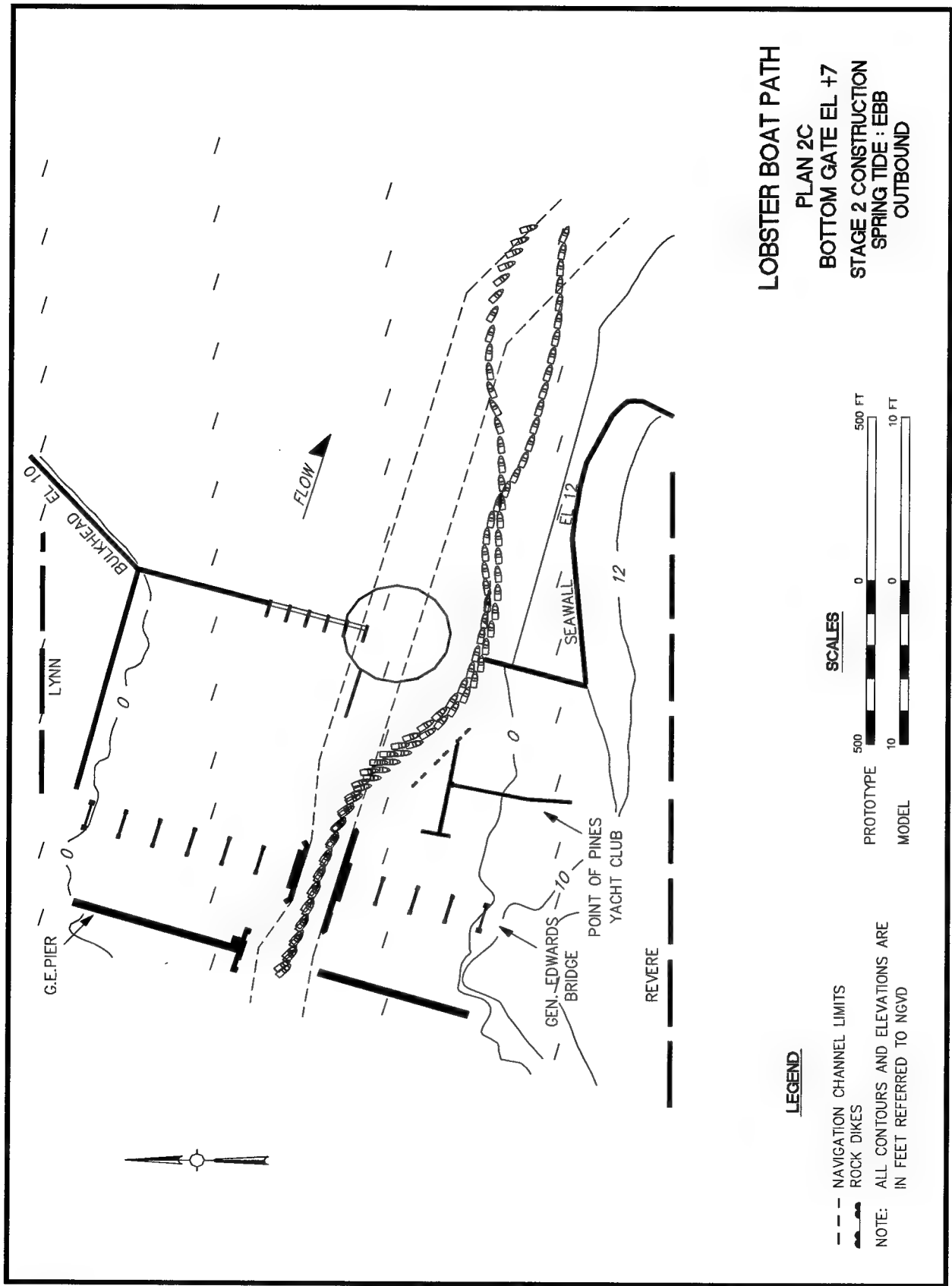


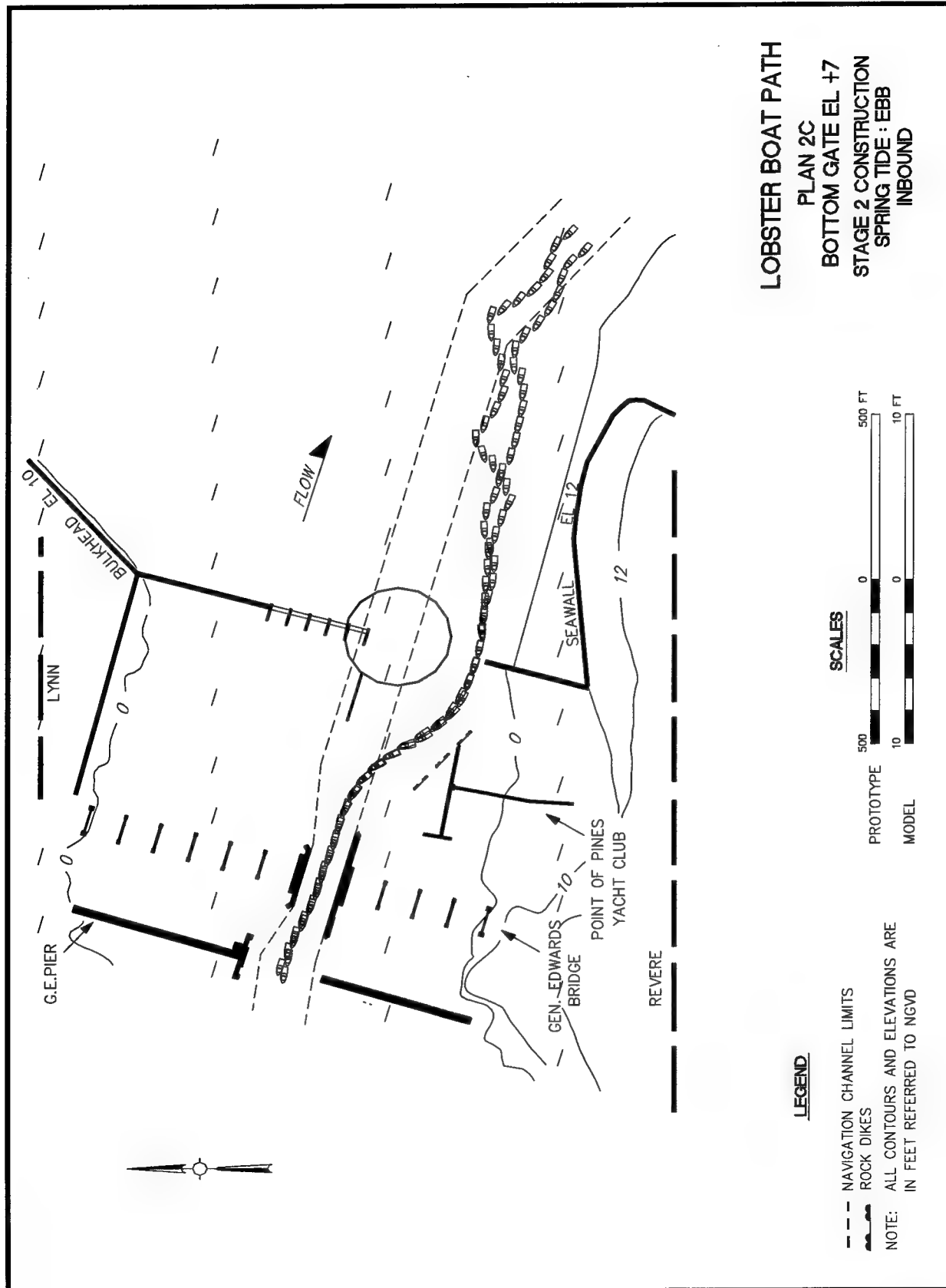
Plate 104



LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL +7
 STAGE 2 CONSTRUCTION
 SPRING TIDE : FLOOD
 OUTBOUND



LOBSTER BOAT PATH
 PLAN 2C
 BOTTOM GATE EL +7
 STAGE 2 CONSTRUCTION
 SPRING TIDE : EBB
 OUTBOUND



Appendix A

Group Visits to WES

Visitor	Affiliation
Headquarters, U.S. Army Corps of Engineers	
Sam Powell ^{1,2}	Chief, Hydraulic Design, CECW-ED-D
New England Division	
Bob Hunt ^{1,2}	Project Manager, Prj. Mgt. Div., Programs/ Project Mgt Directorate
Greg Buteau ^{1,2}	Engineering Manager, Eng. Mgt. Div., Engineering Directorate
Chuck Wener ^{1,2}	Chief, Hydraulics and Water Quality Branch, Water Control Div., Eng. Dir.
Frank Fedele ²	Construction Directorate
Paul Schimelfenyg ¹	Geotechnical Engineering Div., Engineering Directorate
St. Louis District	
Walter Wagner ^{1,2}	Mechanical/Electrical Section, Design Branch, Engineering Division
Jim Worts ^{1,2}	Structural Section, Design Branch, Engineer- ing Division
Edward Demsky ²	Geotechnical Engineering Division, Engineering Division
Mark Alvey ¹	Geotechnical Engineering Division, Engineering Division
U.S. Coast Guard	
LTJG Pat Foran ²	Aids to Navigation Branch, First C.G. District, Boston
State Sponsors - Metropolitan District Commission^{1,2}	
Carney M. Terzian	Supv., Parks Engineering & Construction Div.
Henry A. Higgott	Project Manager, Parks Engineering and Construction Div.
(Continued)	
¹ 9-11 March 1992	
² 1 July 1992	

Concluded	
City of Lynn	
Steve L. Smith ¹	Assistant City Planner and Conservation Comm.
Joseph L. Ray ²	Lynn Waterways Commission
City of Malden	
John T. Kelly ¹	City Engineer
City of Revere	
Paul A. Cacciola ^{1,2}	Administrative Assistant to Mayor and Point of Pines Yacht Club
Frank Stringi ¹	Director, City Planning Office and Point of Pines Yacht Club
Peter Cacciola ²	Harbor Master and Point of Pines Yacht Club
Town of Saugus	
Edward J. Collins, Jr. ²	Saugus Town Manager
Joseph Attubato ²	Saugus Director of Public Works
William Robinson ¹	Lobsterman, Saugus Harbor Commission, Atlantic Lobstermen's Coop.
Waterways Experiment Station^{1,2}	
Larry Daggett	Chief, Navigation Branch, Waterways Division, Hydraulics Laboratory
Howard Park	Research Hydraulic Engineer, Navigation Branch, Waterways Division, Hydraulics Laboratory
Ronald Wooley	Navigation Branch, Hydraulics Laboratory
Dave Richards	Chief, Estuarine Simulation Branch, Estuaries Division, Hydraulics Laboratory
Jerry Lin	Research Hydraulic Engineer, Estuarine Engineering Branch, Estuaries Division, Hydraulics Division
Jimmy Brogdon	Research Hydraulic Engineer, Estuarine Simulation Branch, Estuaries Division, Hydraulics Laboratory

Appendix B

Plan 2C

Bottom of Gate at el +7

Reduced Dredging Along

South Shore

Description

Plan 2C, with bottom of gate at el +7 and a reduced dredging plan along the south shore, is shown in Plate B1. This plan is the same as Plan 2C with bottom of gate at el +7 (Figure 9) with one exception: The dredge cut along the south shore near the city of Revere was reduced to what is believed to be the minimum size. The dredge cut was normal to the floodgate structure about 200 ft seaward and then angled toward the navigation channel to a point about 500 ft seaward of the floodgate structure. The influence of breaching the I-95 embankment was included in these tests.

Results

Current direction and velocities

Current direction and velocity data are shown in Plates B2 and B3. Current direction and velocity data for the spring tide and flood flow (Plate B2) indicate that current magnitudes were about the same as those observed with Plan 2C +7. The most noticeable difference was the direction of the north-to-south cross-current approaching the navigation gate. The angle of the flow relative to the center line of the navigation gate was greater than that observed with Plan 2C +7. The reduction of the dredged cut along the south shore influenced the strength of the crosscurrent approaching the navigation gate.

With the spring tide and ebb flow (Plate B3) current magnitudes were about the same as those observed with Plan 2C +7. However, the influence of reducing the dredge cut along the south shore was observed in the direction of flow seaward of the floodgate structure. With the reduced dredge cut, the flow no longer moved parallel to the south shore as observed with Plan 2C +7, but in a northeasterly direction across the navigation channel seaward of the floodgate structure.

Navigation conditions

Navigation conditions for small vessels are demonstrated in Plates B4-B7. With the spring tide and flood flow, navigation conditions for inbound vessels approaching the navigation gate of the floodgate structure were more difficult than those observed with Plan 2C +7 (Plate B4). The angle of the crosscurrent approaching the navigation gate was greater. This in turn caused the vessel to encroach on the south pier of the navigation gate more than observed with Plan 2C +7. Navigation conditions for outbound vessels approaching the navigation gate were about the same as those observed with Plan 2C +7. However, once through the navigation gate, outbound vessels were pushed toward the south shore more than observed with Plan 2C +7.

With the spring tide and ebb flow, navigation conditions were also more difficult than those observed with Plan 2C +7 (Plates B6 and B7). However, the difficulties associated with reducing the dredge cut along the south shore occurred seaward of the floodgate structure in open water. It is for this reason that the changes induced by reducing the dredge cut were believed to have little impact on safe navigation.

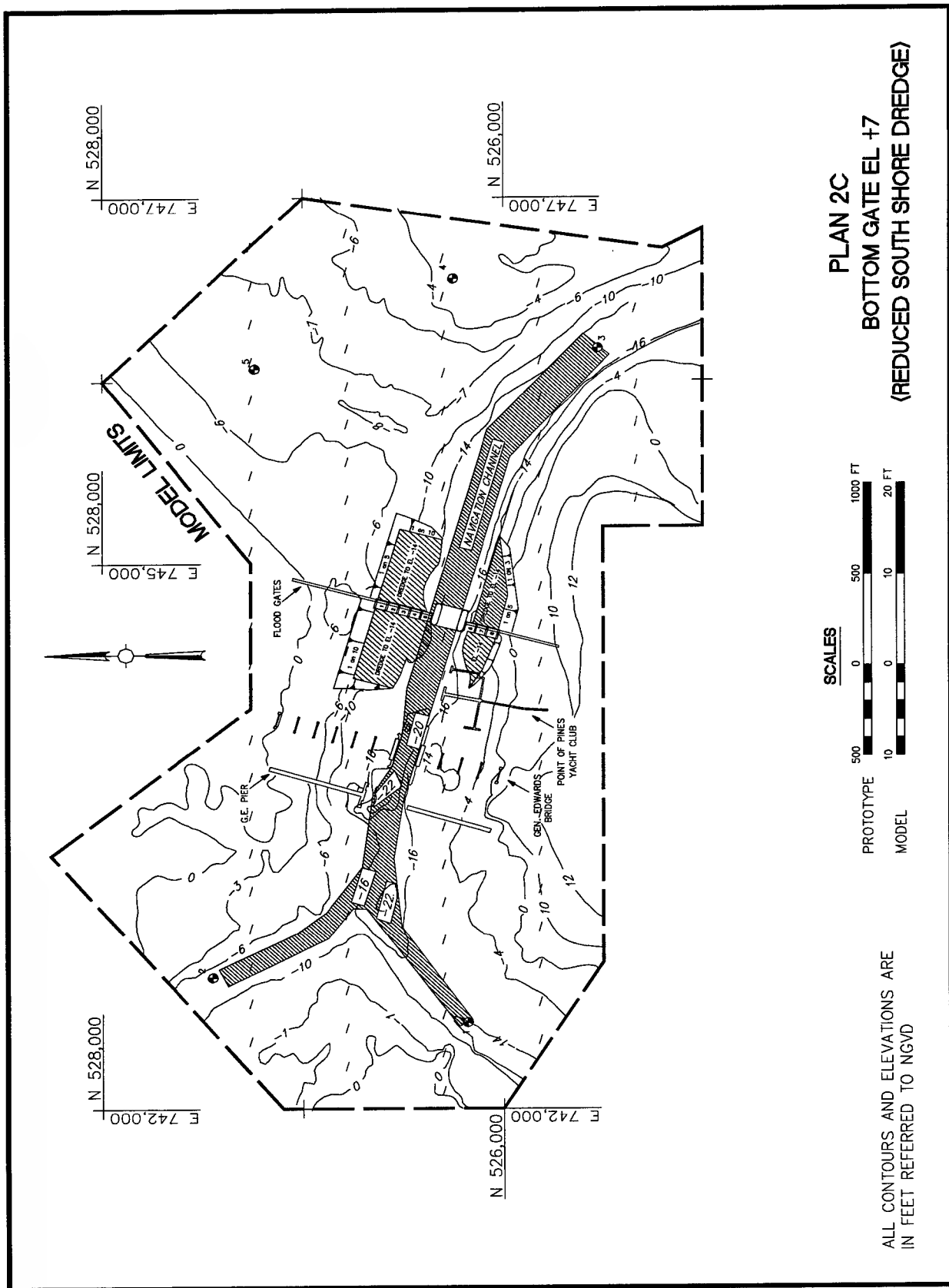


Plate B1

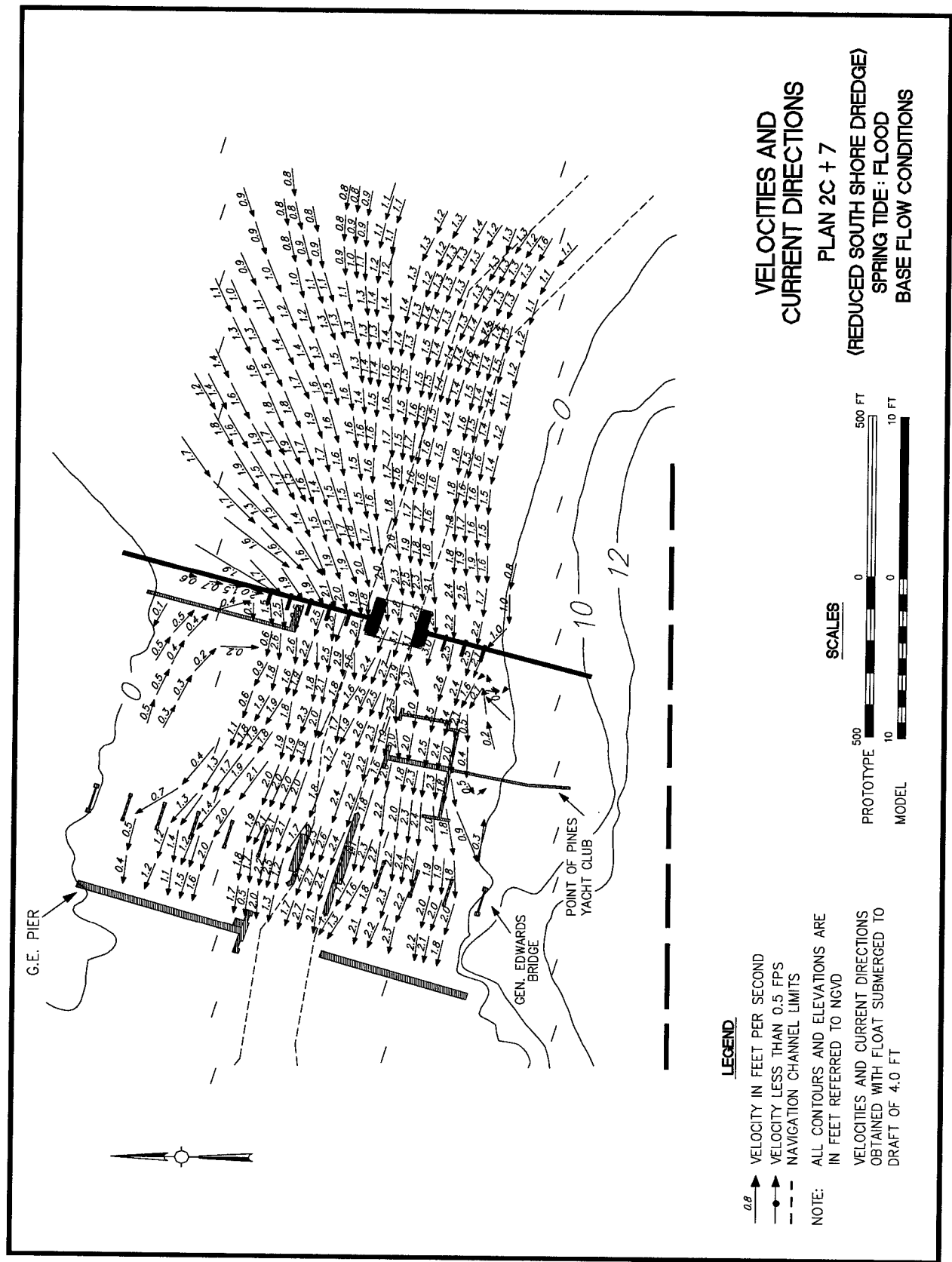
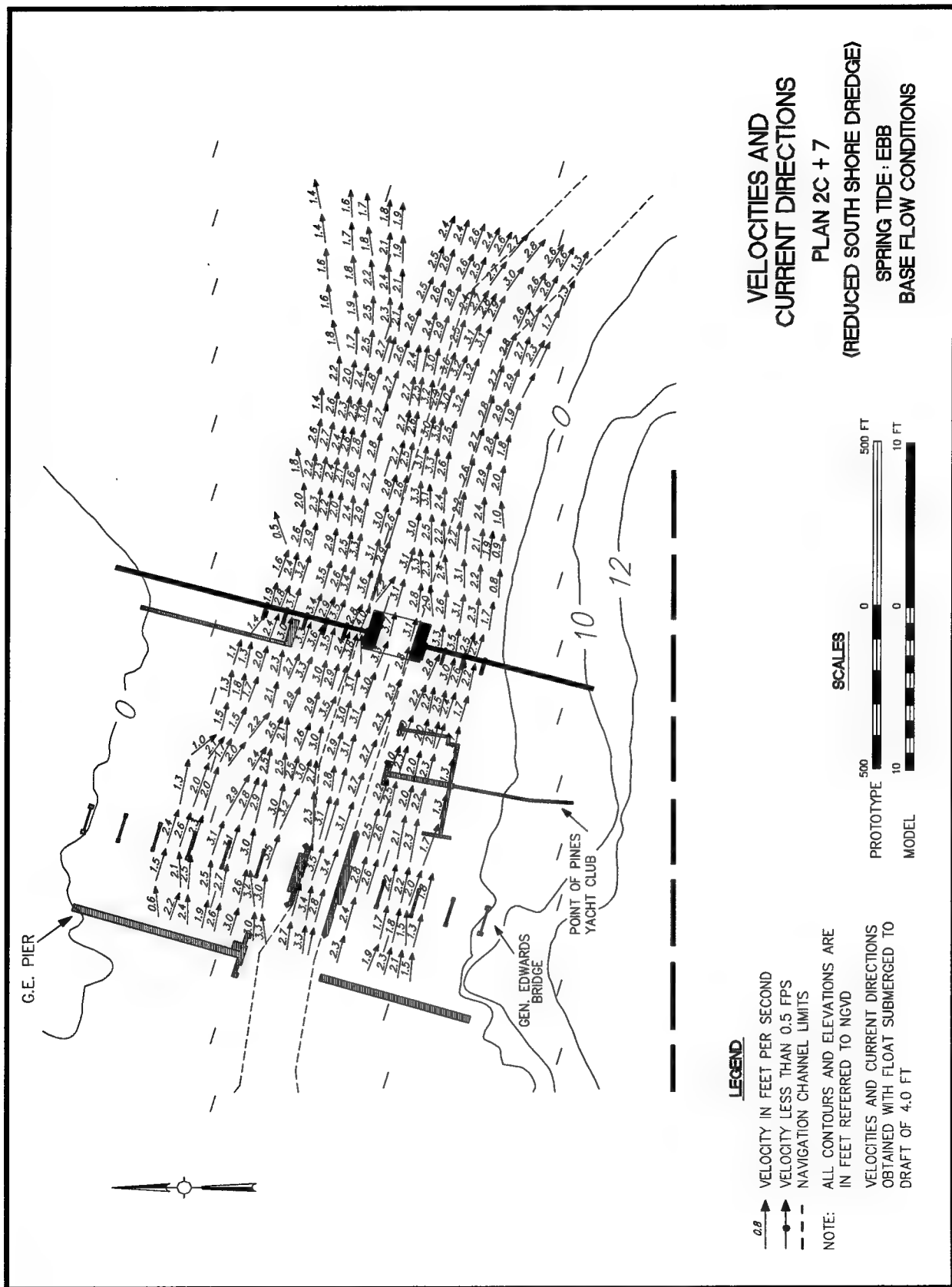


Plate B2



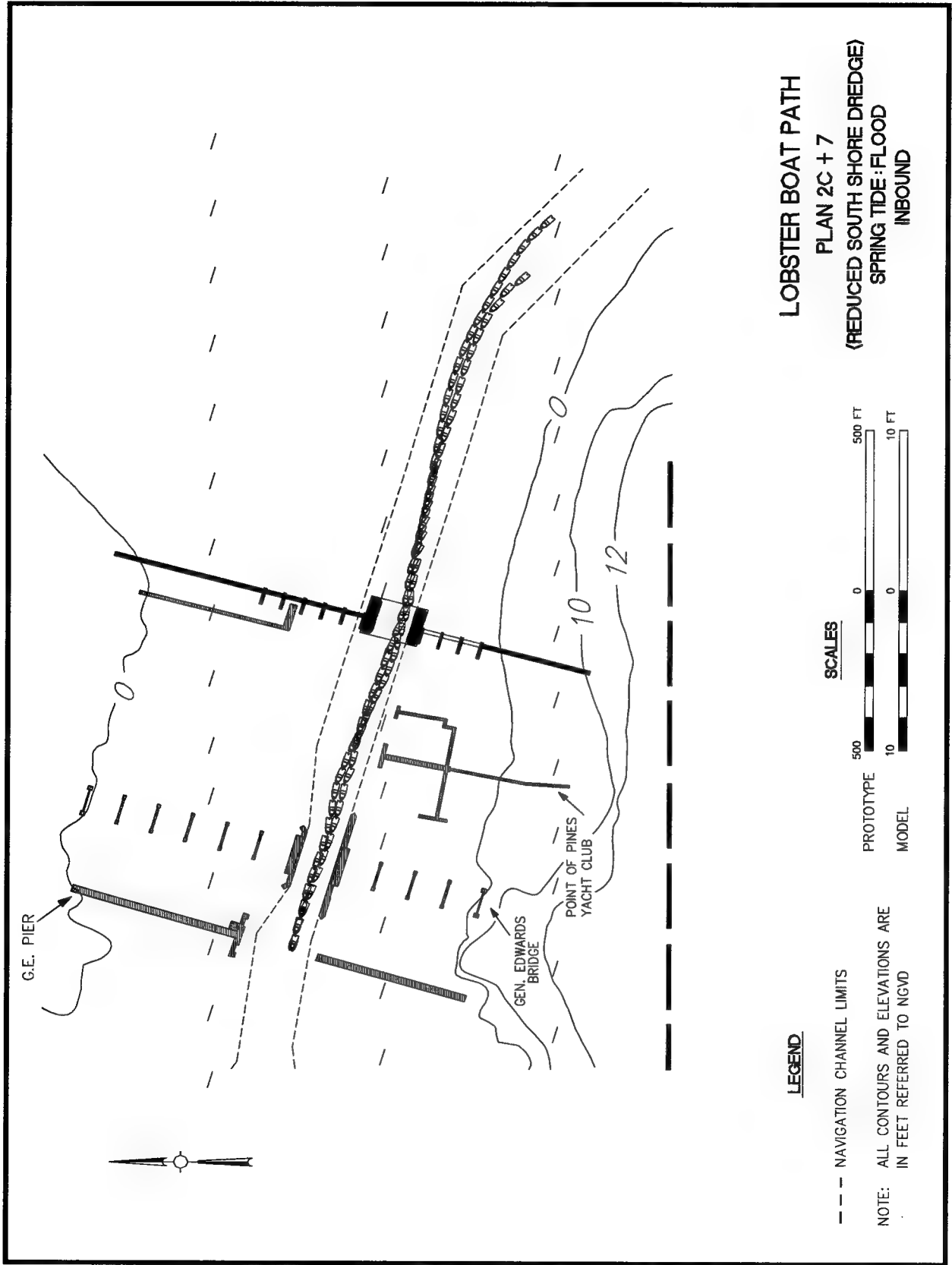


Plate B4

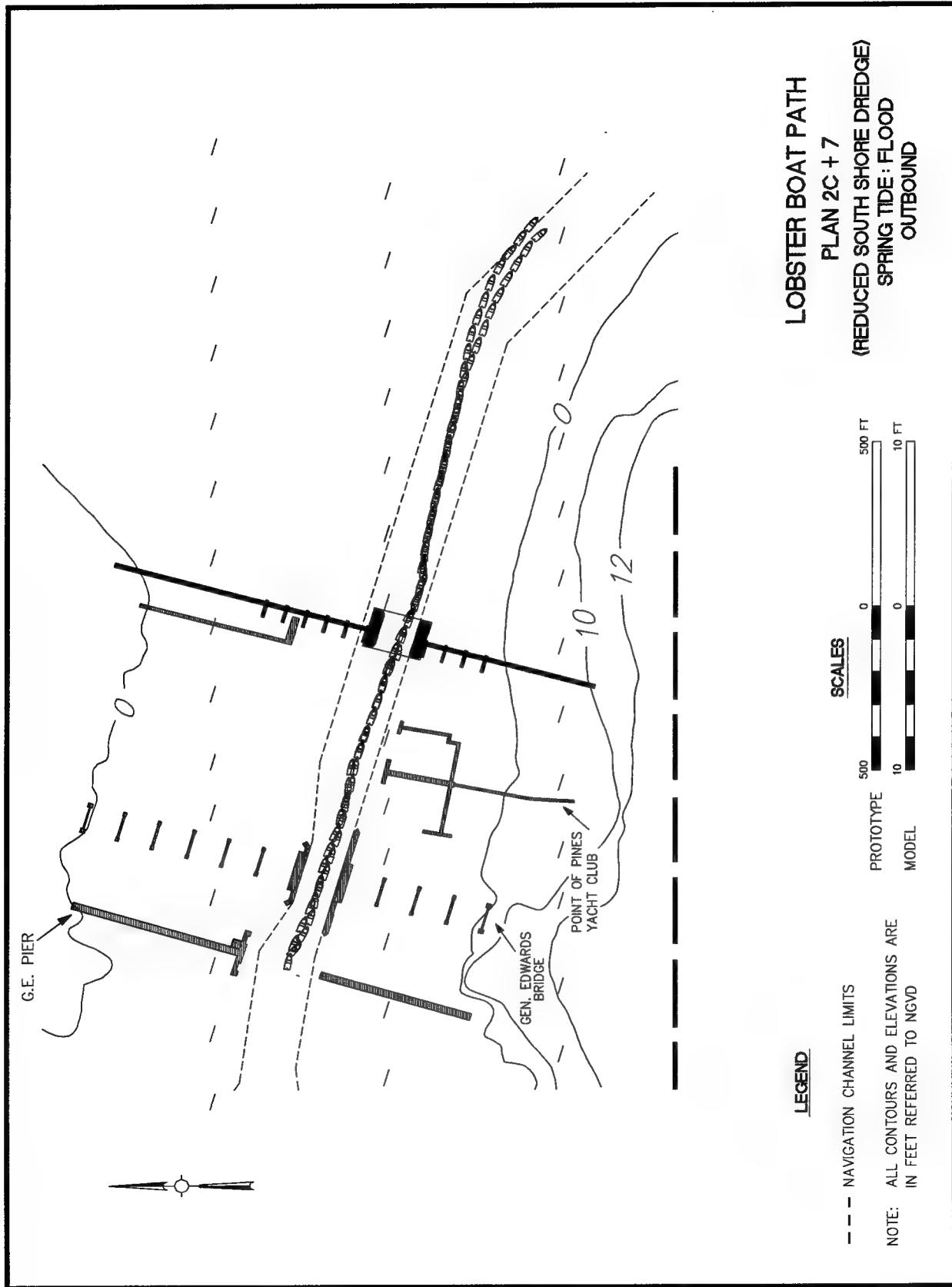


Plate B5

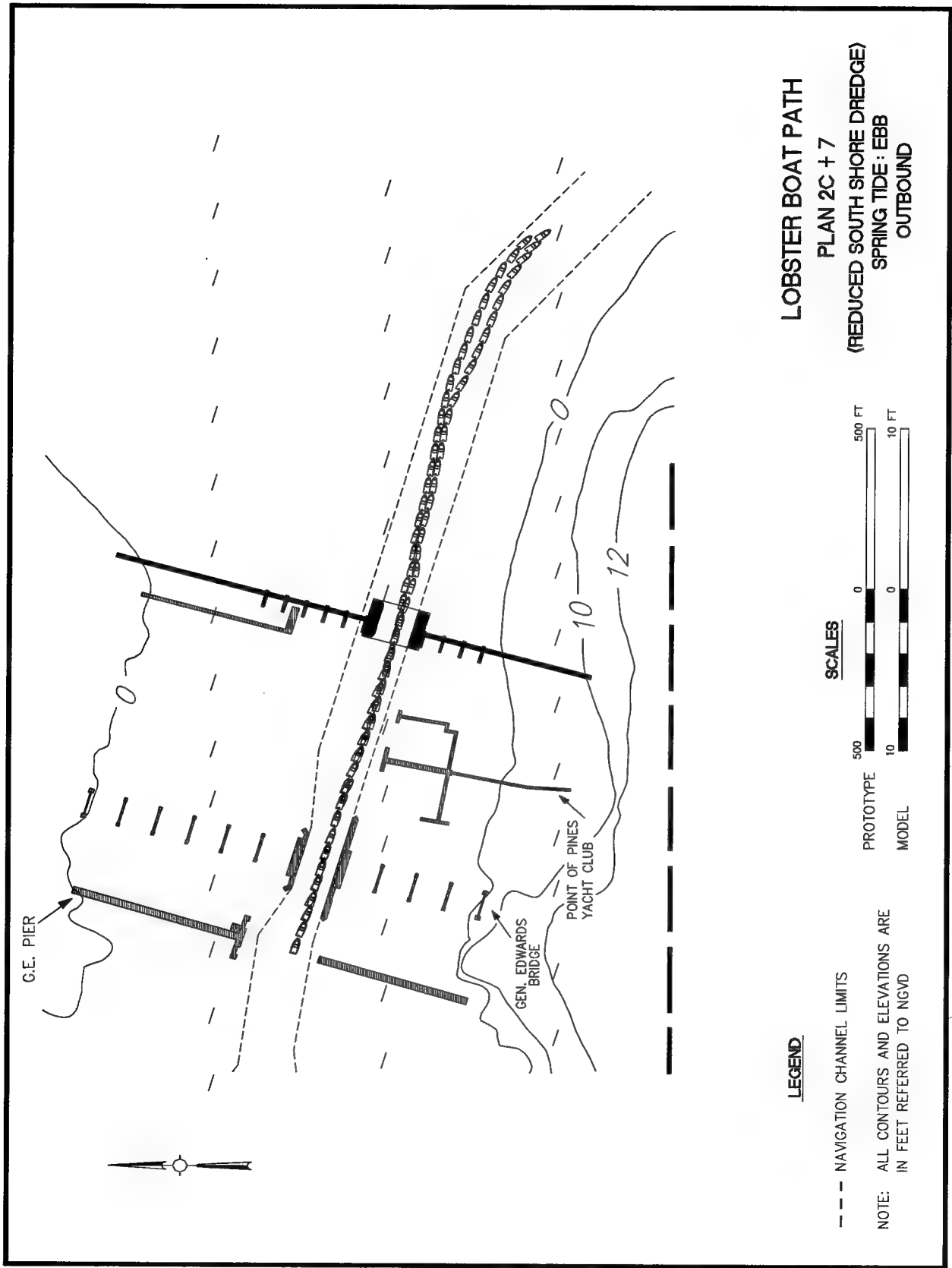


Plate B6

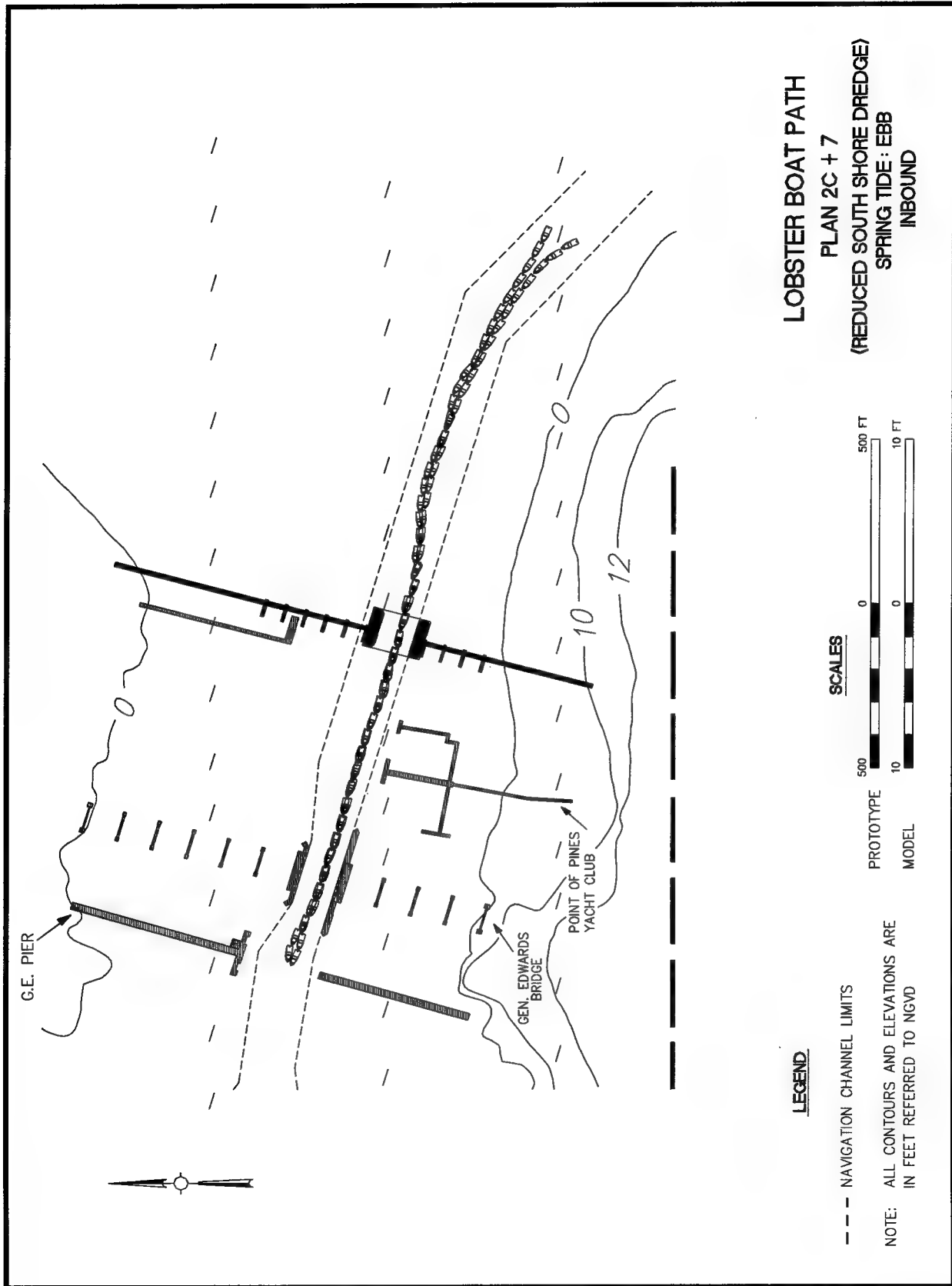
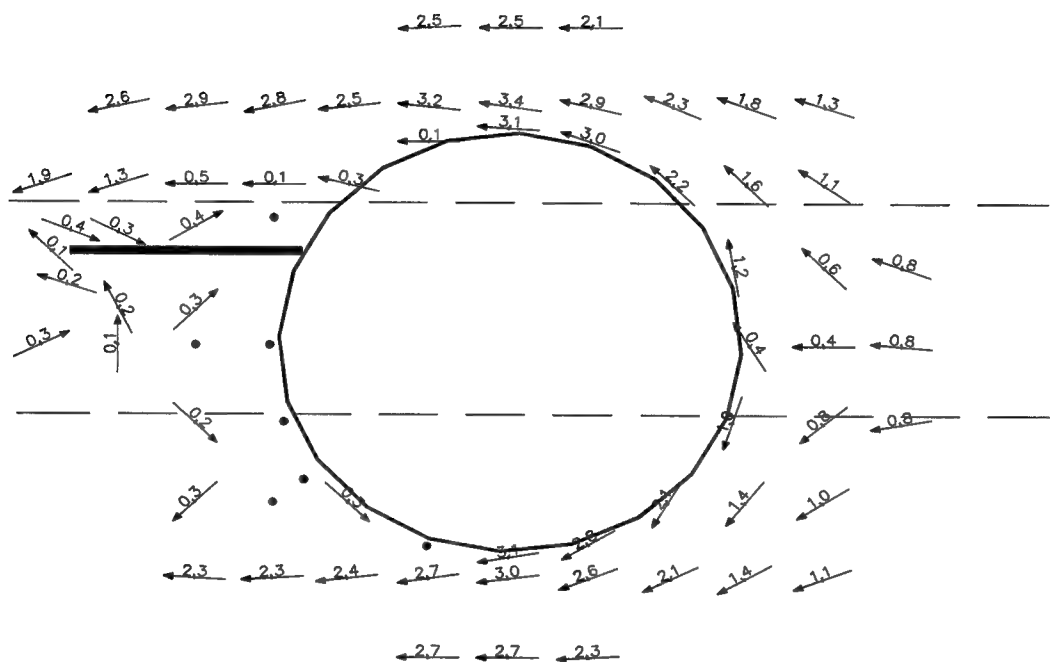


Plate B7

Appendix C

Meter Velocities and Water Surface Elevations



LEGEND

PROTOTYPE

100 0 100 200 300 FT

MODEL

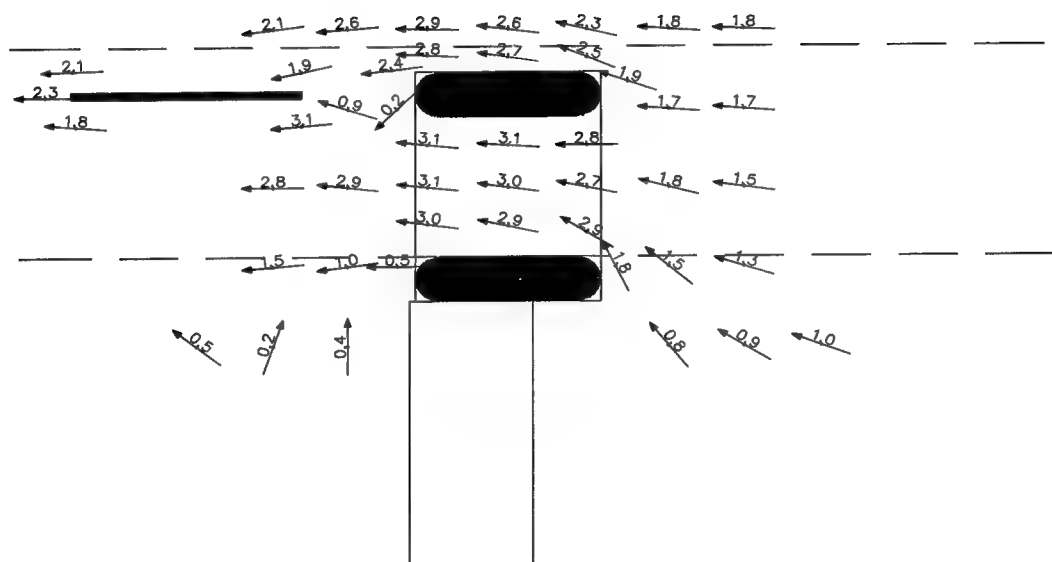
2 0 2 4 6 FT

LEGEND

NOTE: VELOCITY MEASUREMENTS RECORDED
NEAR CHANNEL BOTTOM
← 3.2 VELOCITY IN FEET PER SECOND
• INDICATES VELOCITY LESS THAN 0.1 FPS

METER VELOCITIES
STAGE 1 CONSTRUCTION
SPRING TIDE : FLOOD

Plate C1



LEGEND



LEGEND

NOTE: VELOCITY MEASUREMENTS RECORDED
NEAR CHANNEL BOTTOM

← 3.2 VELOCITY IN FEET PER SECOND

• INDICATES VELOCITY LESS THAN 0.1 FPS

METER VELOCITIES
STAGE 2 CONSTRUCTION
SPRING TIDE : FLOOD

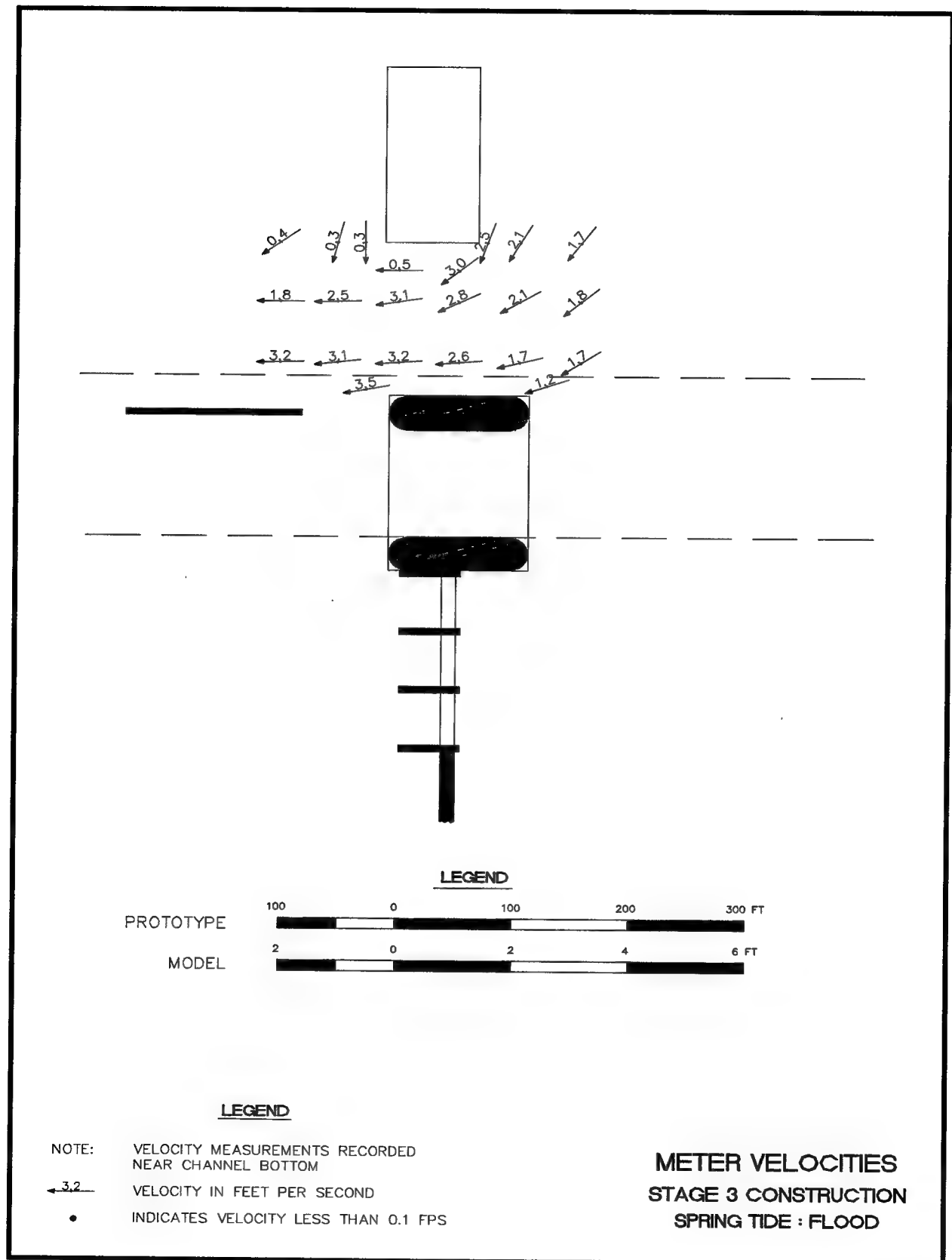


Plate C3

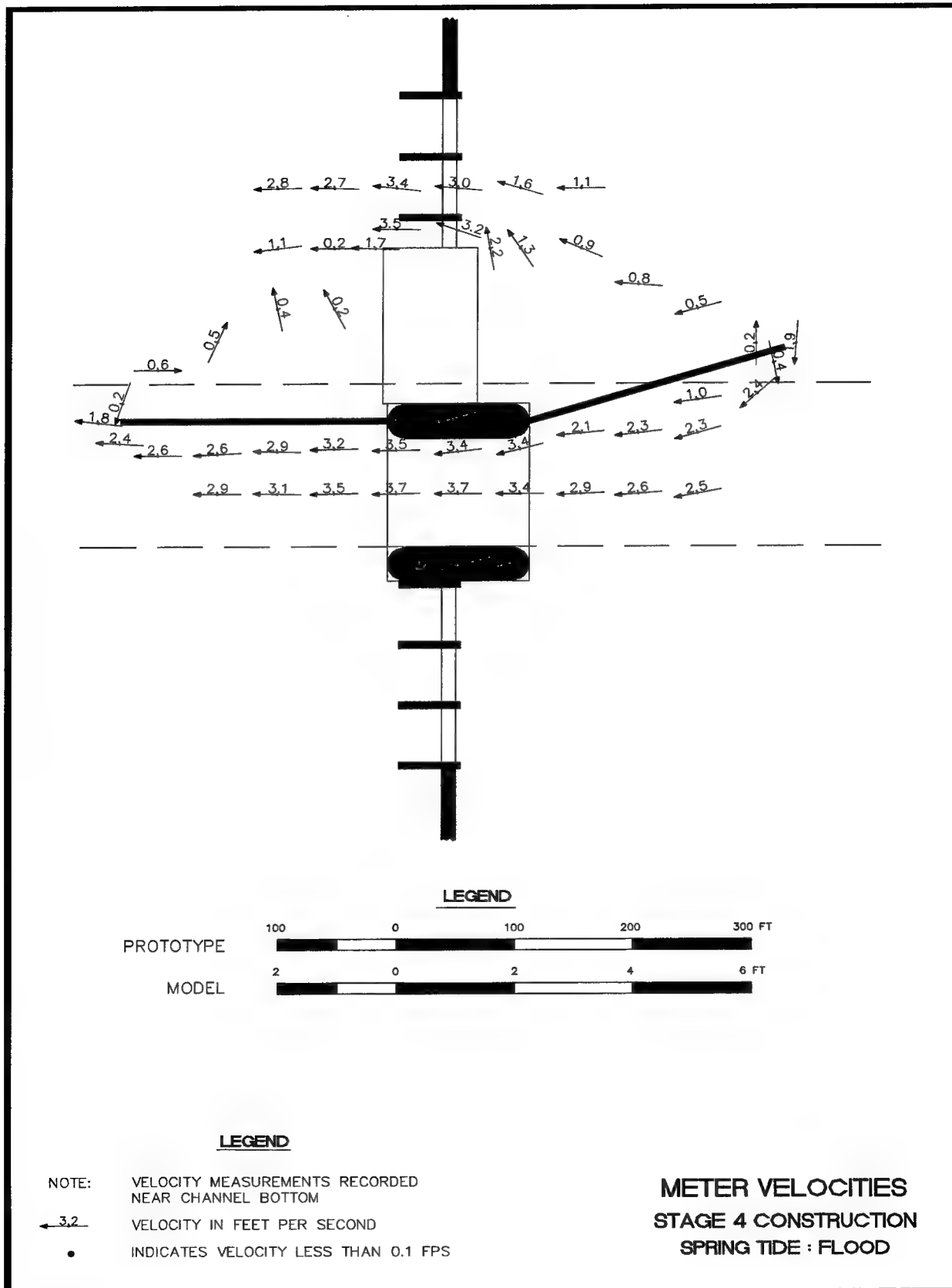
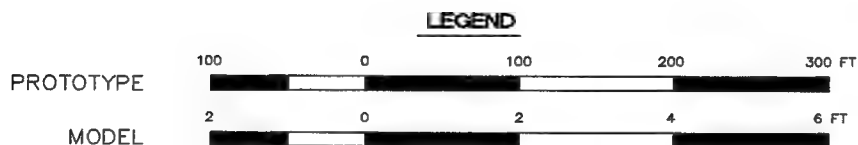
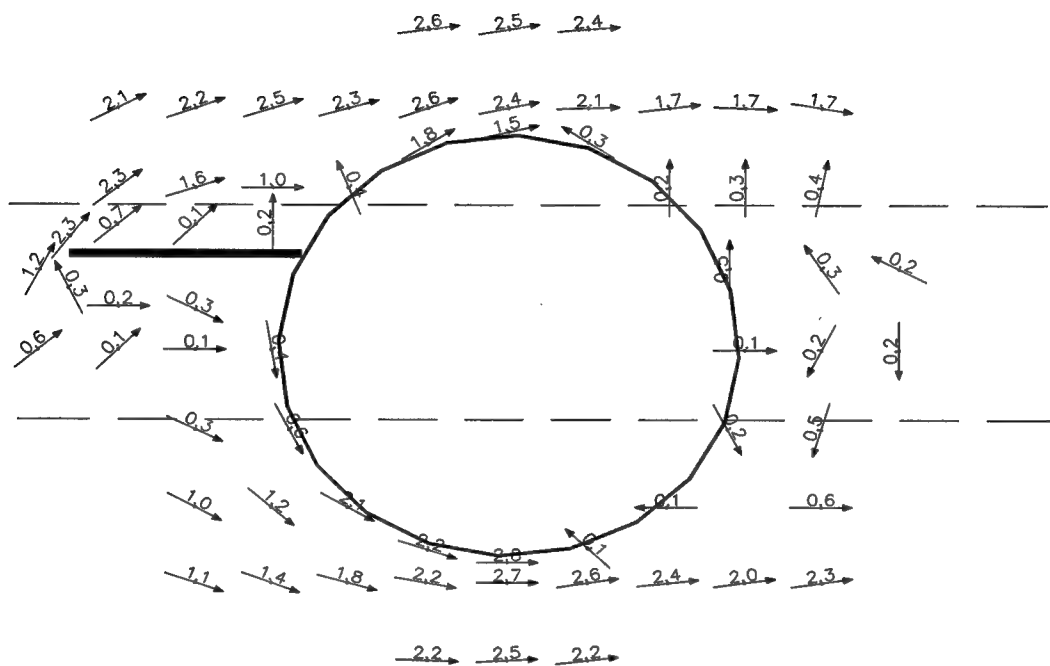


Plate C4



LEGEND

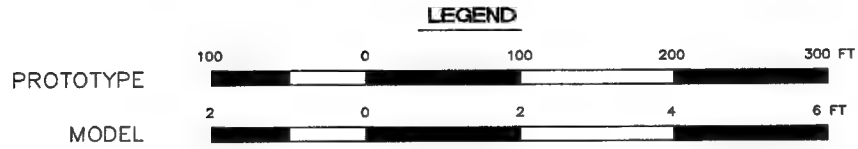
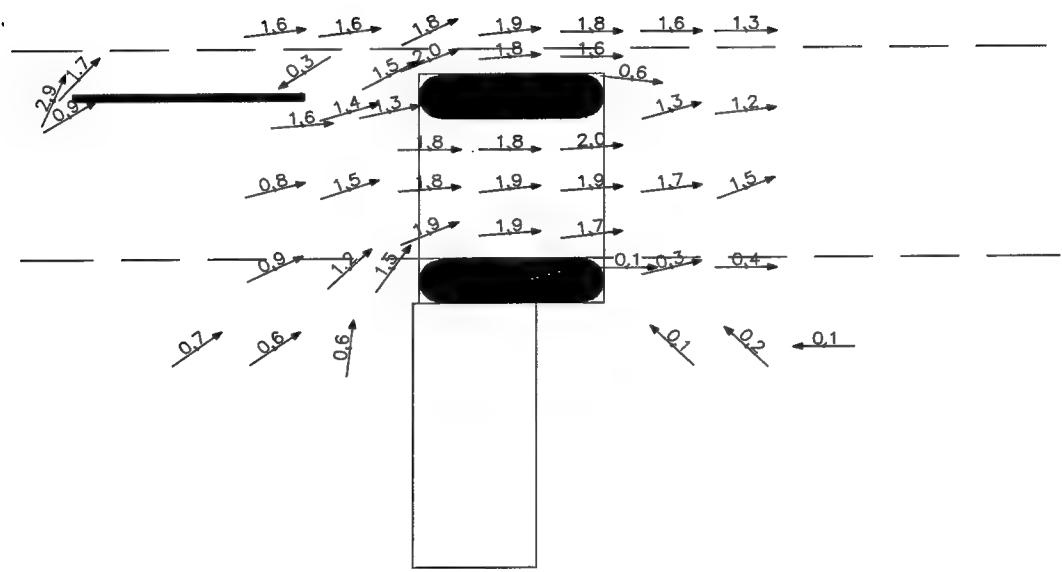
NOTE: VELOCITY MEASUREMENTS RECORDED
NEAR CHANNEL BOTTOM

← 3.2 → VELOCITY IN FEET PER SECOND

• INDICATES VELOCITY LESS THAN 0.1 FPS

**METER VELOCITIES
STAGE 1 CONSTRUCTION
SPRING TIDE : EBB**

Plate C5



LEGEND

NOTE: VELOCITY MEASUREMENTS RECORDED NEAR CHANNEL BOTTOM

← 3.2 VELOCITY IN FEET PER SECOND

• INDICATES VELOCITY LESS THAN 0.1 FPS

METER VELOCITIES
STAGE 2 CONSTRUCTION
SPRING TIDE : EBB

Plate C6

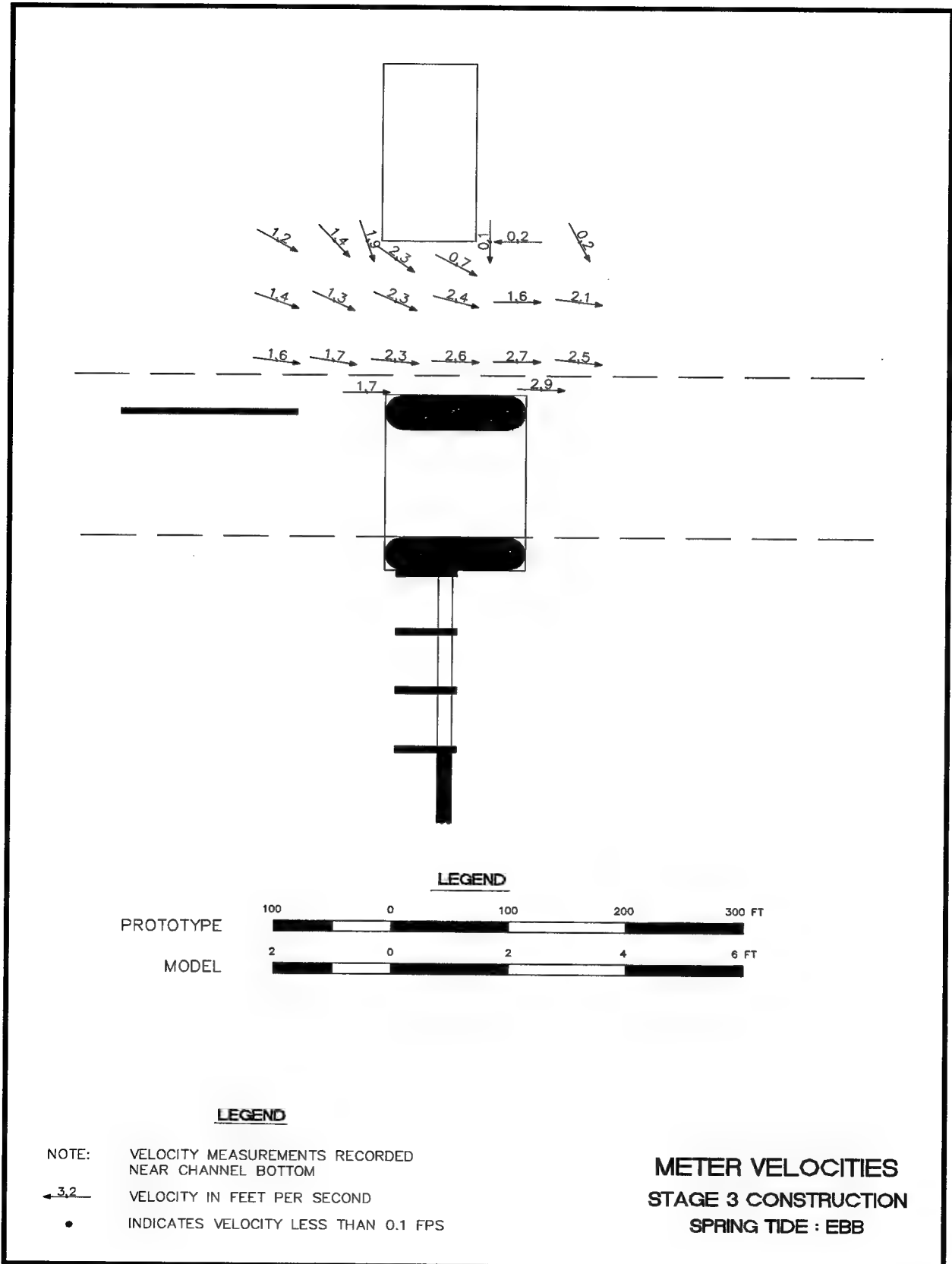


Plate C7

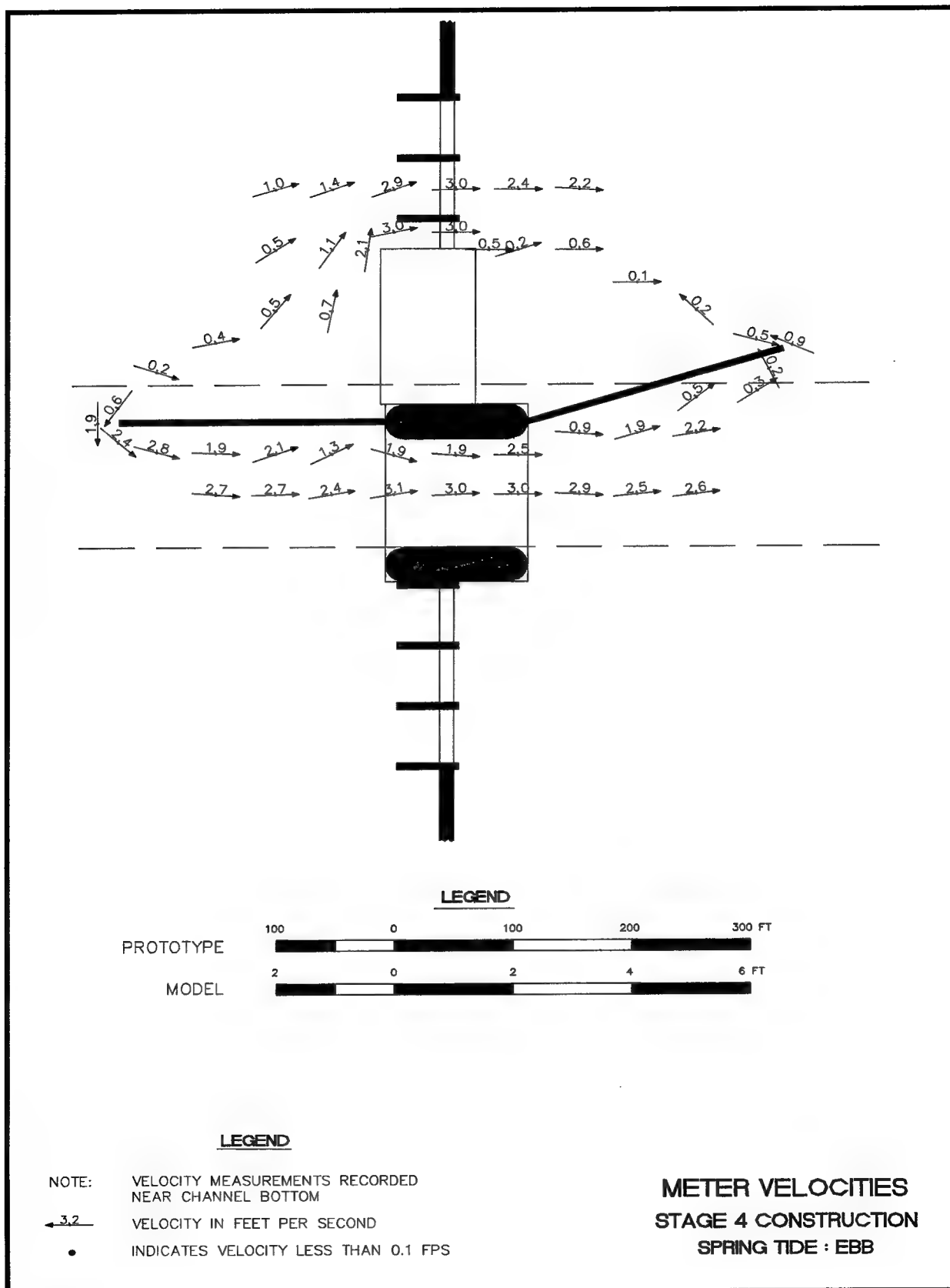


Plate C8

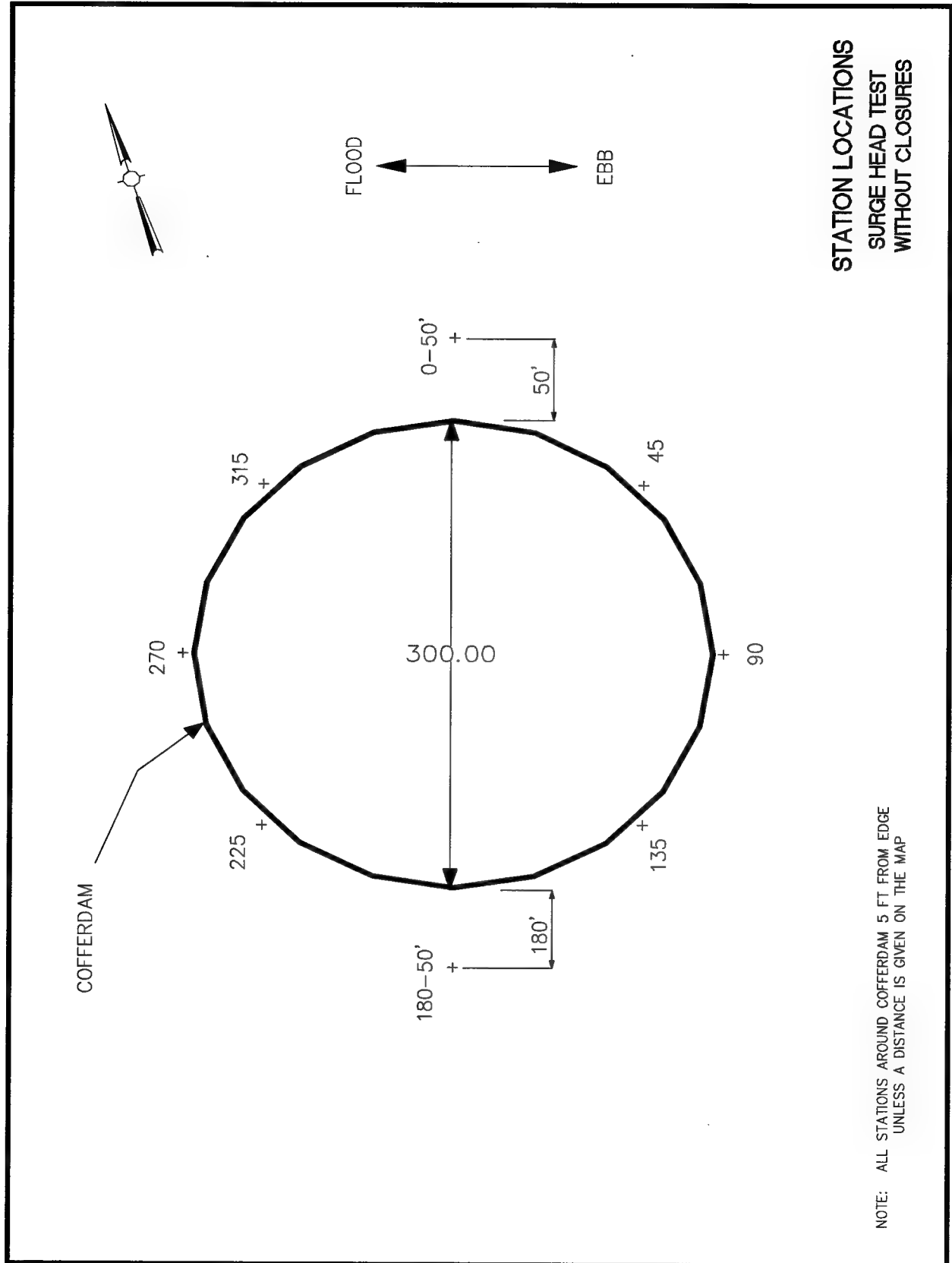


Plate C9

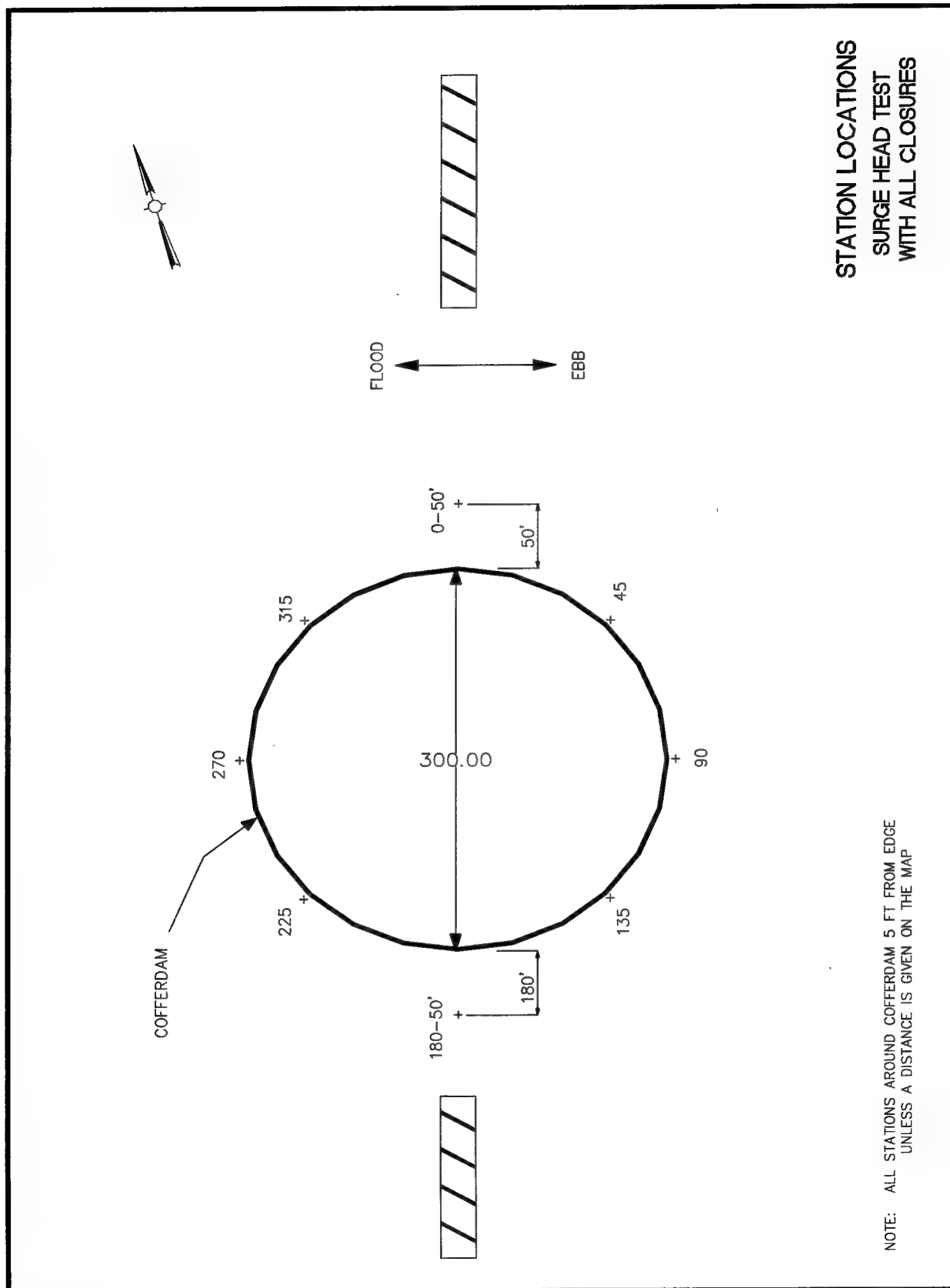


Plate C10

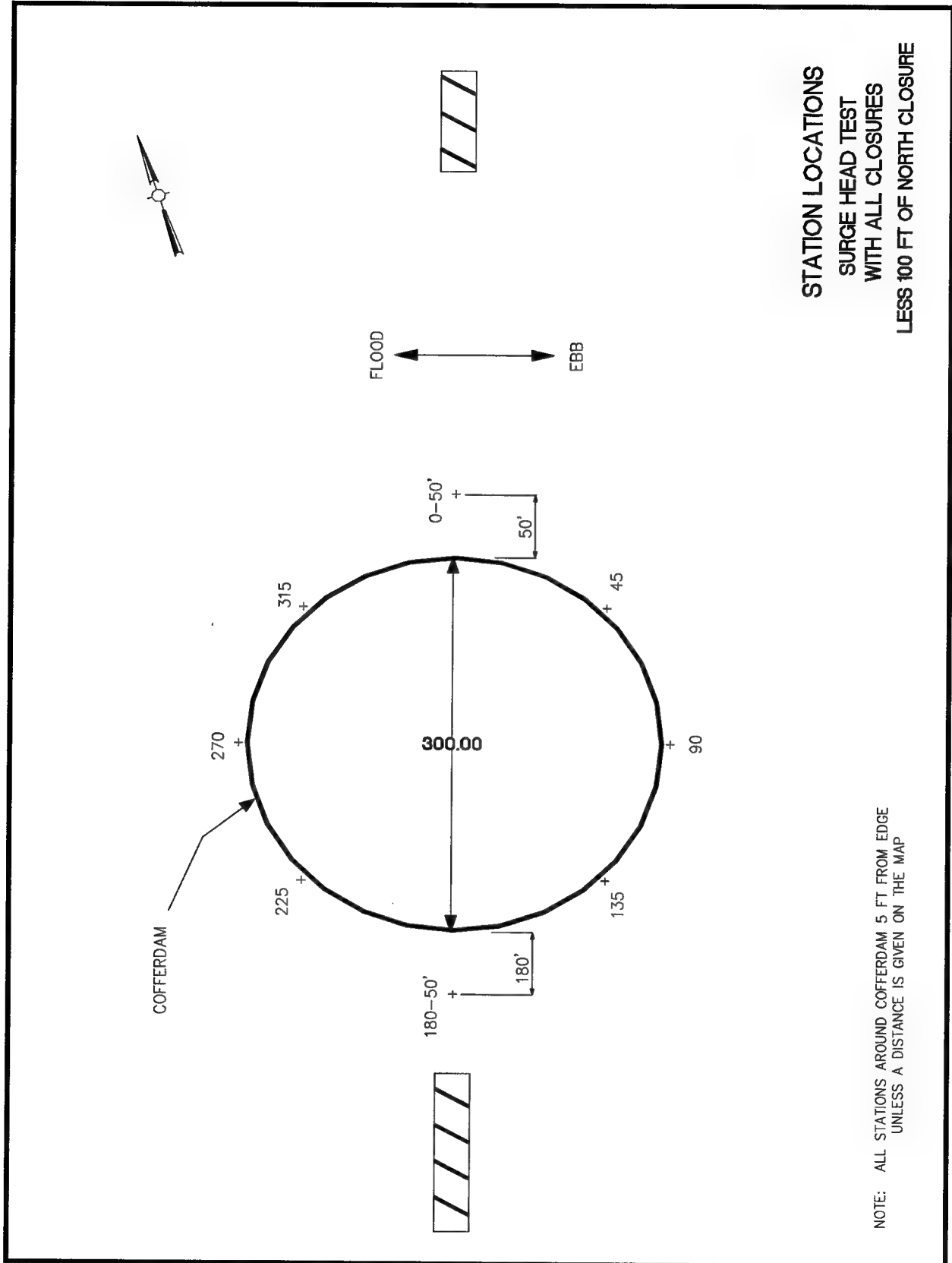
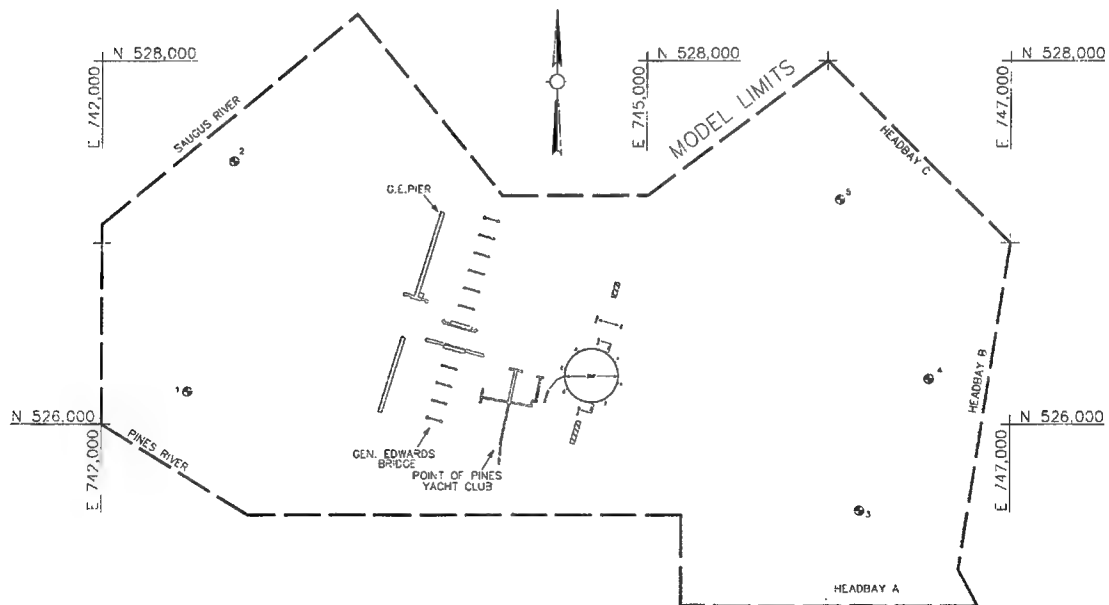


Plate C11

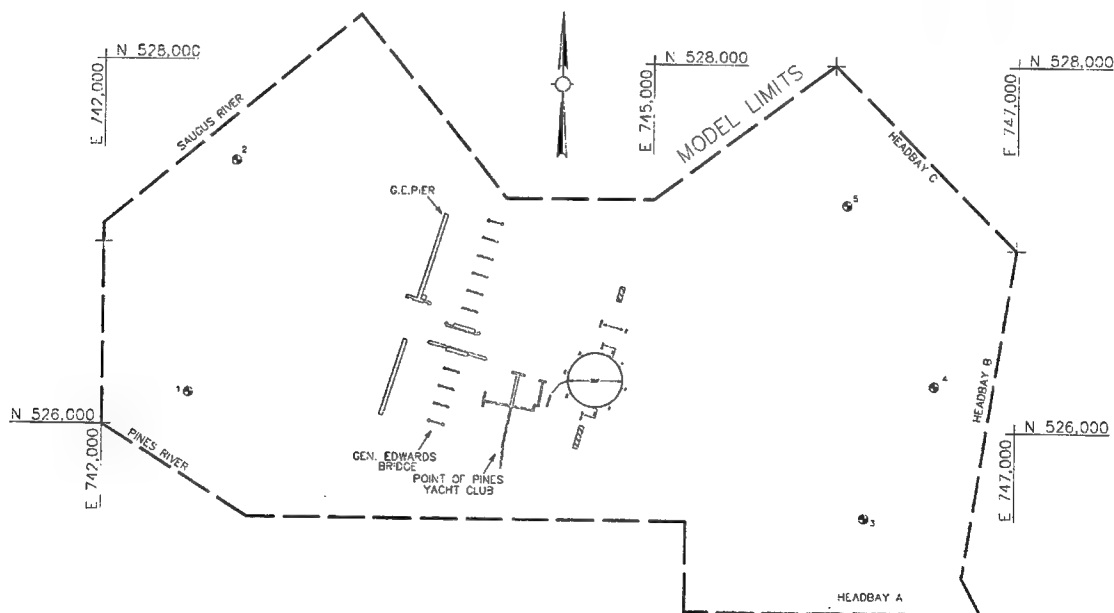
Stations	Surge Head, ft		
	Without closures	With all closures -100 ft of north closure	With all closures
Pines River	3.15	3.13	3.08
Saugus River	3.18	3.10	3.05
Headbay A	3.48	3.48	3.48
Headbay B	3.48	3.50	3.50
Headbay C	3.48	3.50	3.50
0	3.15	3.05	2.98
0-50'	3.18	3.13	3.05
45	3.33	3.38	3.35
90	3.40	3.48	3.48
135	3.30	3.25	3.23
180	3.15	3.08	2.98
180-50'	3.20	3.15	3.05
225	3.28	3.13	3.03
270	3.28	3.10	3.05
315	3.20	3.13	3.05



**WATER-SURFACE ELEVATIONS
EXISTING SPRING FLOOD**

Plate C12

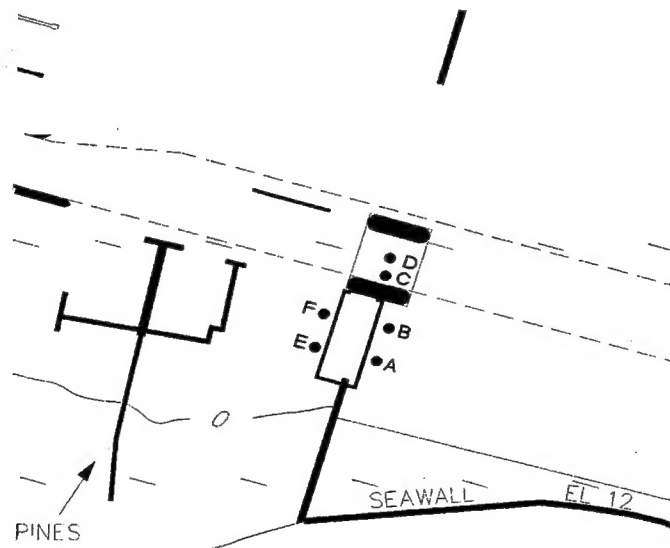
Stations	Surge Head, ft		
	Without closures	With all closures -100 ft of north closure	With all closures
Pines River	4.95	4.95	4.95
Saugus River	4.98	4.98	4.98
Headbay A	4.88	4.73	4.60
Headbay B	4.85	4.75	4.60
Headbay C	4.83	4.75	4.60
0	4.70	4.70	4.53
0-50'	4.70	4.65	4.55
45	4.78	4.70	4.58
90	4.83	4.73	4.55
135	4.83	4.70	4.53
180	4.75	4.70	4.53
180-50'	4.80	4.78	4.63
225	4.88	4.80	4.73
270	4.95	5.00	4.88
315	4.92	4.90	4.80



WATER-SURFACE ELEVATIONS
EXISTING SPRING EBB

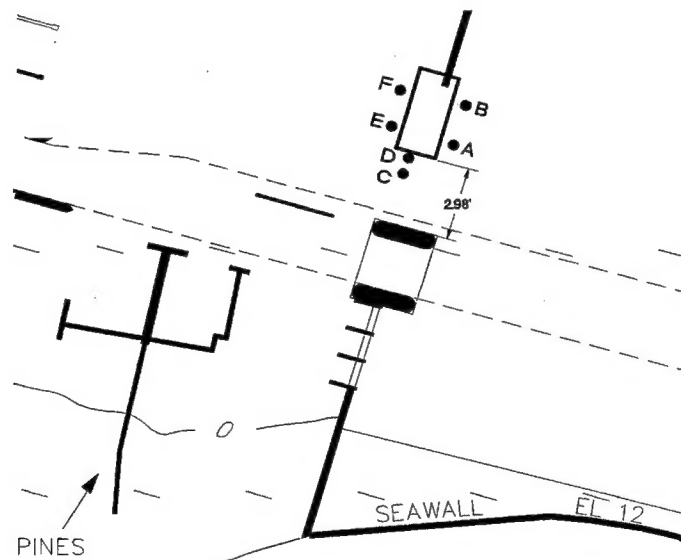
Plate C13

Stations	Surge Head, ft	
	Flood	EBB
Pines River (1)	3.10	4.98
Saugus River (2)	3.18	5.00
Headbay A (3)	3.48	4.75
Headbay B (4)	3.50	7.73
Headbay C (5)	3.48	4.73
2-A	3.48	4.73
2-B	3.43	4.70
2-C	3.13	4.75
2-D	3.18	4.73
2-E	3.13	4.93
2-F	3.15	4.95



WATER-SURFACE ELEVATIONS
EXISTING SPRING TIDE
STAGE 2

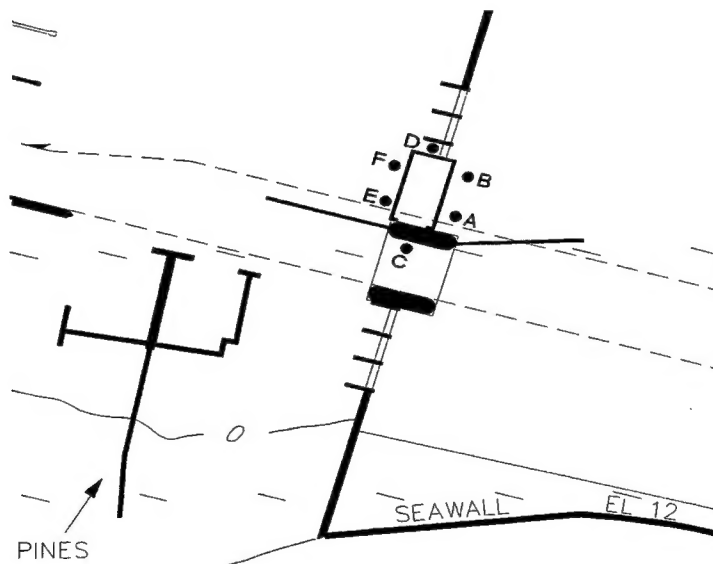
Stations	Surge Head, ft	
	Flood	EBB
Pines River (1)	3.18	4.95
Saugus River (2)	3.20	4.98
Headbay A (3)	3.48	4.75
Headbay B (4)	3.48	4.75
Headbay C (5)	3.48	4.75
3-A	3.40	4.70
3-B	3.43	4.73
3-C	3.18	4.70
3-D	3.18	4.70
3-E	3.18	4.90
3-F	3.18	4.90



WATER-SURFACE ELEVATIONS
EXISTING SPRING TIDE
STAGE 3

Plate C15

Stations	Surge Head, ft	
	Flood	EBB
Pines River (1)	3.10	4.95
Saugus River (2)	3.15	4.98
Headbay A (3)	3.48	4.68
Headbay B (4)	3.48	4.70
Headbay C (5)	3.48	4.68
4-A	3.45	4.58
4-B	3.43	4.58
4-C	3.20	4.63
4-D	3.18	4.68
4-E	3.13	4.90
4-F	3.18	4.93



WATER-SURFACE ELEVATIONS
EXISTING SPRING TIDE
STAGE 4

Plate C16

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12b.DISTRIBUTION CODE**13.ABSTRACT (Maximum 200 words)**

Because of flooding that has occurred at the mouth of the Saugus and Pines River estuary about 10 miles north of Boston, MA, and because of the potential for additional flooding and costly damage, the U.S Army Engineer Division, New England, has developed a plan to reduce flood damage from the Standard Project Northeaster (SPN). The plan consists of construction of a revetment, seawalls, restored sand dunes, and the Saugus River floodgate structure.

Although the design for the proposed floodgate was based on sound theoretical design practice and experience, navigation conditions through the navigation gate of the structure could be expected to be complex. Therefore, comprehensive numerical and physical model studies were considered necessary. Construction sequencing of the floodgate structure and navigation of vessels through each phase of construction for both ebb and flood tides were accomplished in the physical model, and are documented in this report.

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